A STUDY OF POROSITY AND PERMEABILITY IN BITUMINOUS MIXTURES

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc. Prof. Ir. Dr. Hj. Ibrahim Kamaruddin)

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TRONOH, PERAK

July 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Idzmil Haffiz Mohamad Nor

ABSTRACT

This report provides an insight into the content of the project and its significance, namely *'A study of porosity and permeability in bituminous mixtures'*. The study is divided into two (2) elements which cover the porosity and permeability of a bituminous mixture. Both elements focus on different bituminous mixtures by varying the types of aggregates and gradations. The types of aggregates used are crushed granite and crushed limestone; and each of them was employed to produce two aggregate gradations, which are well-graded and gap-graded. There is strong evidence from this investigation that porosity and permeability plays an important factor in determining the performance of the bituminous mixture. A number of tests have been conducted to characterize the material used relating to this study and the results were compared with the specifications of the Jabatan Kerja Raya (JKR). Parallel to the investigation on the amount of porosity and permeability characteristics of the mixtures, the study was further continued to analyze the performance of the bituminous mixtures. Performance tests relating to deformation (rutting) and fatigue (cracking) were conducted. There is reason to believe that granite with gap-graded gradation is a better highway building material as it performed better in terms of rutting and fatigue cracking. All the observations and results gathered were discussed in this report.

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I would like to take this opportunity to express my gratitude to all parties and individuals, in particular whose help and guidance has made my Final Year Project a success. Above all, I would like to convey my utmost gratitude to Universiti Teknologi PETRONAS (UTP) who has structured a good course and make it a great educational session.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

'A study of porosity and permeability in bituminous mixtures', as the topic suggest is to investigate the amount of porosity (See **Figure 1.1**) and permeability (See **Figure 1.2**) in various bituminous mixtures. The first truly bituminous mixtures were produced in the 1870s in Paris, and were first used in the UK around the turn of century, although they were no extensively available until the 1930's (Hunter, 1994). Basically, bituminous mixtures are a combination of mineral aggregates (i.e coarse aggregates and fine aggregates), filler and bitumen as a based binder.

The term porosity is a measure of the void spaces in a material (in this case, bituminous mixtures), while permeability is the connectivity or continuity of the voids, which gives the passageway or flow between the voids. Both factors play an important role in describing the pavement's performance. In varying the combination of type of aggregates and gradations in the bituminous mixtures, a study will be conducted to determine the amount of porosity and permeability for each respective aggregate combination. Upon completion of the engineering properties of the mixture, performance tests were conducted on the mixture pertaining to their deformation and fatigue performance.

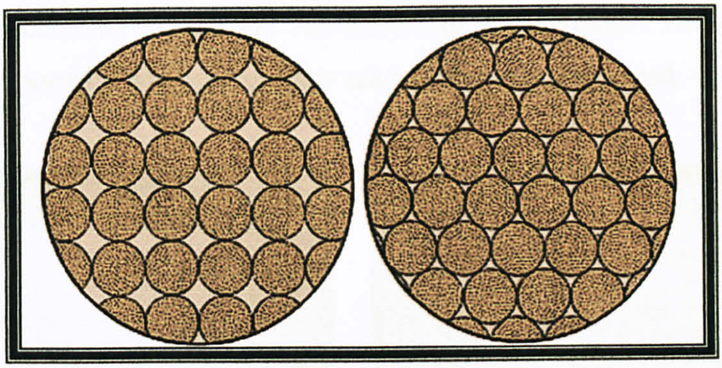

Figure 1.1 *: Porosity*

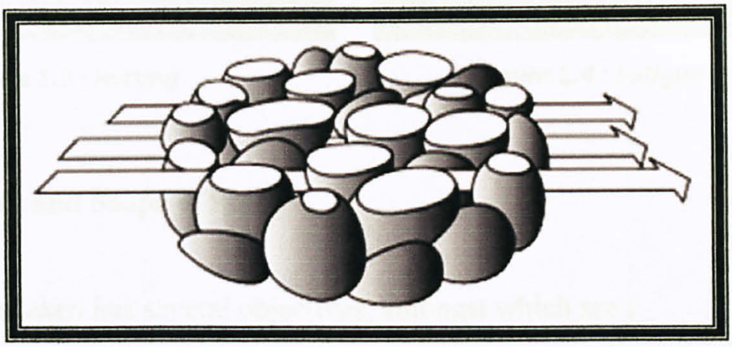

Figure 1.2 *: Permeability*

1.2 Problem Statement

Over the past 20 years, there has been an aggressive growth of traffic on pavements and concerns about safety issues, driver comfort, and cost on maintenance (Francken, 1998). A lot of research has been conducted towards preventing the various distresses in highway materials. Some of the prominent distresses are fatigue cracking (See **Figure 1.3**), rutting (See **Figure 1.4**), and stripping and these distresses issues are related to porosity and permeability of the material after compaction in highways. Moreover, it has cause implication on the cost of the highway building materials.

Porosity and permeability are important factors in determining the characteristics of the bituminous mixture. Both elements relate to cracking and rutting issues in the mix. Rutting happens when a depression or groove are developed into a road due to the traffic loads. Different types of aggregates and gradations will produce different amount of porosity and permeability to the mix. The durability of the mixture will also be affected if the amount of porosity and permeability are not properly addressed.

Figure 1.3 : *Rutting*

Figure 1.4 : *Fatigue Cracking*

1.3 Objectives and Scope of Study

The study undertaken has several objectives, amongst which are :

i) Investigate the amount of porosity and permeability in bituminous mixtures for different aggregate types and gradation

ii) Analyze the result of the study and relate to the performance of the bituminous mixtures when employed as highway construction materials

iii) To suggest the best bituminous mixture based on the results and analysis conducted

The scope of the study is associated with the construction of highways in urban environments. The project will cover the mix design method and tests on the material porosity and permeability characteristics. The investigations will be in the form of laboratory experiments and data analysis. The types of aggregates involved are crushed *Granite* and crushed *Limestone*. Two (2) different gradations are employed in the mixes namely *Well Graded* and *Gap Graded*, Bitumen of Grade 80/100 and filler consisting of

Ordinary Portland Cement (OPC) were used. Finally, the output of the study is expected to provide information for performance analysis.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Theory

2.1.1 Bituminous Mixtures

A bituminous mixture is composed of a mix of aggregates and bitumen (binder). The graded aggregates consist of coarse and fine aggregates and filler material. Bitumen asphalt is the pre-dominant binder material used nowadays and the term 'asphalt mixture' is now commonly used. Bituminous mixture is also referred as asphalt mixture to detonate the composition (Tia, 2003). The design of a bituminous mix involves the choice of *aggregate type*, *aggregate grading*, bitumen grade and the determination of the bitumen content which will optimize the engineering properties in relation to the desired behavior in service. For pavement application, asphalt mixtures are normally classified by (1) their methods of production or (2) their composition and characteristics. In this report, only the classification by their composition and characteristics are mentioned since both relate to the objectives of this study.

<u>Classification by Composition and Characteristics</u>

Dense-graded Hot Mix Asphalt (HMA) is commonly used as surface and binder courses in asphalt pavements and have a relatively low air voids. They consist of well-graded aggregates and have good structural and frictional characteristics. Tia (2003) stated that the term *Asphalt Concrete* is commonly used to refer to a high-quality, dense-graded HMA mixture.

Stone Matrix Asphalt (SMA), which are high in durability have been found to improve resistance towards rutting (Tia, 2003). The materials used are gap-graded aggregate which are designed to have high coarse aggregate content, high binder content, and high filler content. The improved rutting resistance of the SMA mixture is attributed to the fact that it carries the load through the coarse aggregate matrix (or the stone matrix), as compared with a dense-graded HMA, which carries the load through the fine aggregate (Tia, 2003).

***Figure 2.1** : Dense-Graded HMA (left) vs. SMA (right)*

2.1.2 Types of Aggregates

Granite

Granite (See Figure 2.2) is an igneous rock of visible crystalline formation and texture. The composition of granite consist of feldspar (usually potash feldspar and oligoclase) and quartz, with a small amount of mica (biotite or muscovite) and minor accessory minerals, such as zircon, apatite, magnetite, ilmenite, and sphene. It is normally whitish or gray with a speckled appearance caused by the darker crystals. Potash feldspar imparts a red or flesh color to the rock. Granites were formed by slowly cooling pockets of magma that were trapped beneath the earth's surface. Extremely slow rates of cooling give rise to a very coarse-grained variety called pegmatite. Granite, along with other crystalline rocks, constitutes the foundation of the continental masses, and it is the most common intrusive rock exposed at the earth's surface (Microsoft®, 2009).

The specific gravity of granite ranges from 2.63 to 2.75. Its crushing strength ranges from 1050 to 14,000 kg per sq cm (15,000 to 20,000 lb per sq in). Granite has greater strength than sandstone, limestone, and marble and is correspondingly more difficult to quarry. It is an important building material, the best grades being extremely resistant to weathering (Microsoft®, 2009).

Limestone

Limestone (See **Figure 2.3**) is a common sedimentary rock composed primarily of the mineral calcite ($CaCO_3$). The specific gravities of limestone ranges from 2.65-2.75 for high calcium limestones and 2.75-2.9 for dolomitic limestones. Limestone constitutes approximately 10 percent of the sedimentary rocks exposed on the earth's surface. It is formed either by direct crystallization from water (usually seawater) or by accumulation of shell and shell fragments. The principal component of limestone is the mineral calcite, but limestone frequently also contains the minerals dolomite ($CaMg(CO_3)_2$) and aragonite ($CaCO_3$). Pure calcite, dolomite, and aragonite are clear or white. However, with impurities, they can take on a variety of colors. Consequently, limestone is commonly light colored; usually it is tan or gray. However, limestone has been found in almost every color. The color of limestone is due to impurities such as sand, clay, iron oxides and hydroxides, and organic materials (Microsoft®, 2009).

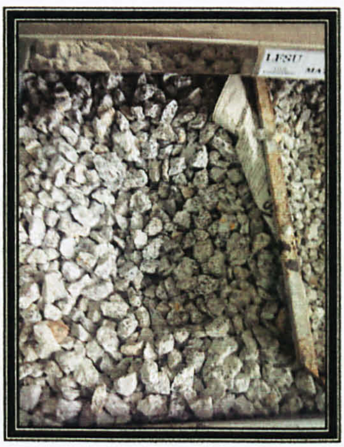

***Figure 2.2** : Granite*

***Figure 2.3** : Limestone*

2.1.3 Aggregate Gradation

The performance of an asphalt mixture is affected by one of the most important characteristics of an aggregate known as, gradation. When the gradation is changed, the properties of an asphalt mixture also changes substantially. Well-graded aggregate gradation produces mixtures with high density with most of the imposed loads from traffic vehicles being borne by the aggregate selection. In gap-graded gradation, the strength of the mixtures is derived from the stiffness of the mortar, thus necessitating the use of harder bitumen in the mix, notably the 50 penetration grade bitumen. The amount of voids or porosity of the mix is an important element in its performance. Phenomena such as bleeding may happen which is caused by limited voids in the mix. When lower asphalt content is used in bituminous mixtures, the asphalt film thickness on the aggregate may also be too low. This would result in a less durable bituminous mix causing the problem of raveling to occur.

Aggregate gradation is often expressed in graphical form. Typically gradation graphs use concepts of maximum density and are expressed in equation form. The Federal Highway Administration (FHWA) 0.45 power graph is often used as a reference check on the gradation.

Well-Graded Gradation

Well-graded gradation (See **Figure 2.4**) refers to a gradation that is near the FHWA's 0.45 power curve for maximum density. Typical gradations are near the 0.45 power curve but not right on it. Generally, a true maximum density gradation (exactly on the 0.45 power curve) would result in unacceptably low Void in Mineral Aggregate (VMA).

Gap-Graded Gradation

Gap-graded gradation (See **Figure 2.5**) refers to a gradation that contains only of a small percentage of aggregate particles in the mid-size range and is flat in this range. Gap graded mixes can be prone to segregation during placement.

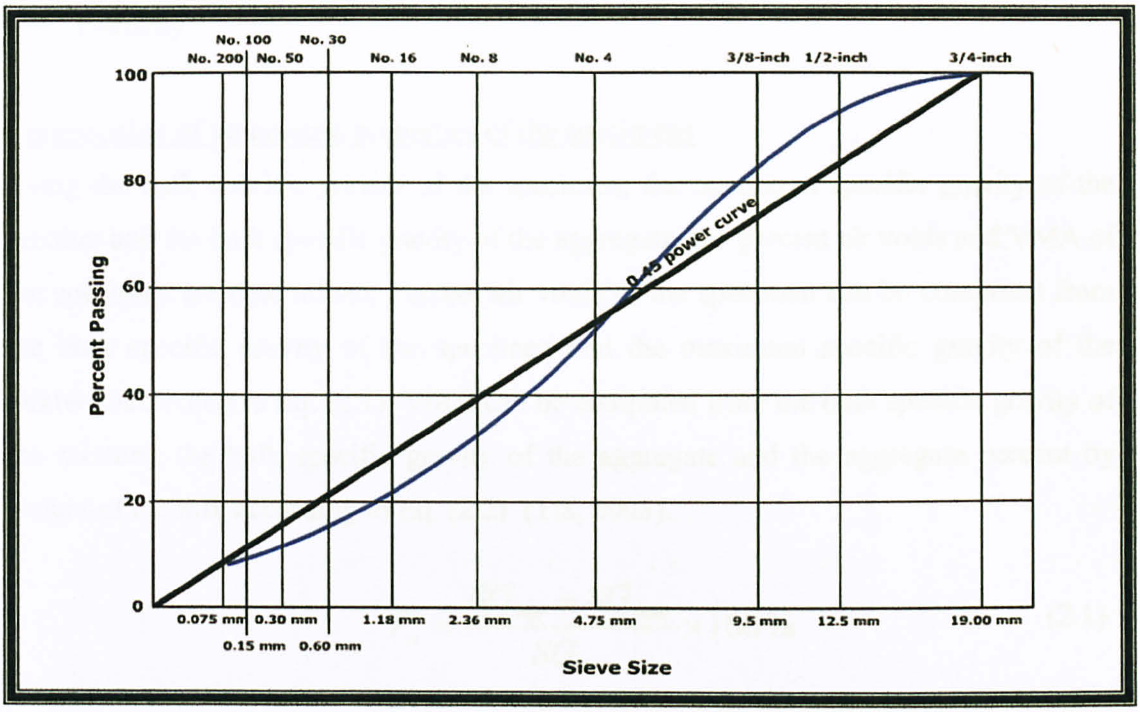

***Figure 2.4** : Well-Graded Gradation Graph*

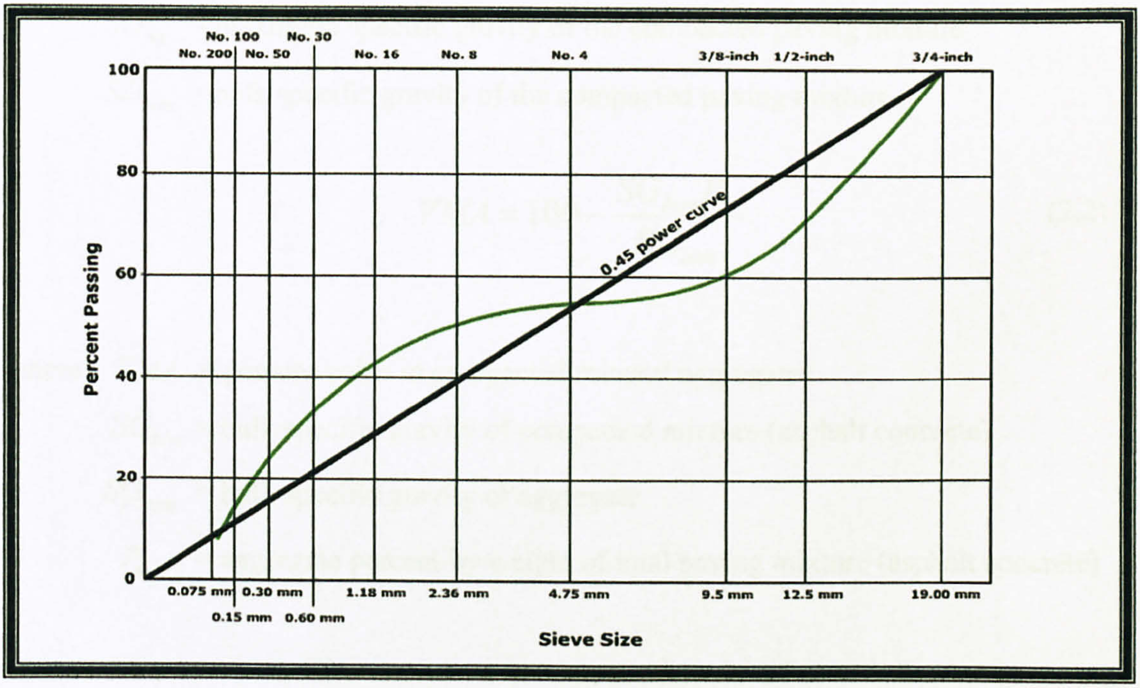

***Figure 2.5** : Gap-Graded Gradation Graph*

2.2 Porosity

Computation of volumetric properties of the specimens

Using the bulk specific gravity of the specimen, the maximum specific gravity of the mixture and the bulk specific gravity of the aggregate, the percent air voids and VMA of the specimen are determined. Percent air voids of the specimen can be computed from the bulk specific gravity of the specimen and the maximum specific gravity of the mixture according to Eq. (2.1). VMA can be computed from the bulk specific gravity of the mixture, the bulk specific gravity of the aggregate and the aggregate percent by weight of the mix according to Eq. (2.2) (Tia, 2003).

$$P_a = \frac{SG_{mp} - SG_{bcm}}{SG_{mp}} \times 100\% \qquad (2.1)$$

where P_{av} = percent air voids in compacted paving mixture

SG_{mp} = maximum specific gravity of the compacted paving mixture

SG_{bcm} = bulk specific gravity of the compacted paving mixture

$$VMA = 100 - \frac{SG_{bcm} P_{ta}}{SG_{bam}} \qquad (2.2)$$

where VMA = percent voids in compacted mineral aggregates

SG_{bcm} = bulk specific gravity of compacted mixture (asphalt concrete)

SG_{bam} = bulk specific gravity of aggregate

P_{ta} = aggregate percent by weight of total paving mixture (asphalt concrete)

2.3 Permeability

Permeameter

The evaluation of air permeability for bituminous mixtures produced in this study is carried out by using a '*Permeameter*' (See **Figure 2.7**) designed in University Technology of PETRONAS. The apparatus is very simple to operate, it is in fact a low technology instrument. It consists of a pressure gauge for measuring the inlet pressure, 2 mm diameter gas inlet, a stainless steel baffle, a silicon cylinder, a steel ring, cell cap, o-ring, stainless steel base and PVC collar. A schematic diagram of the Permeameter is showed in ***Figure 2.6***. The technology uses a compressible gas to measure the permeability and the specimen is prepared in a shape of a core. Thus the sample of bituminous mixtures will be altered into a core shape to fit with the permeameter using a coring machine.

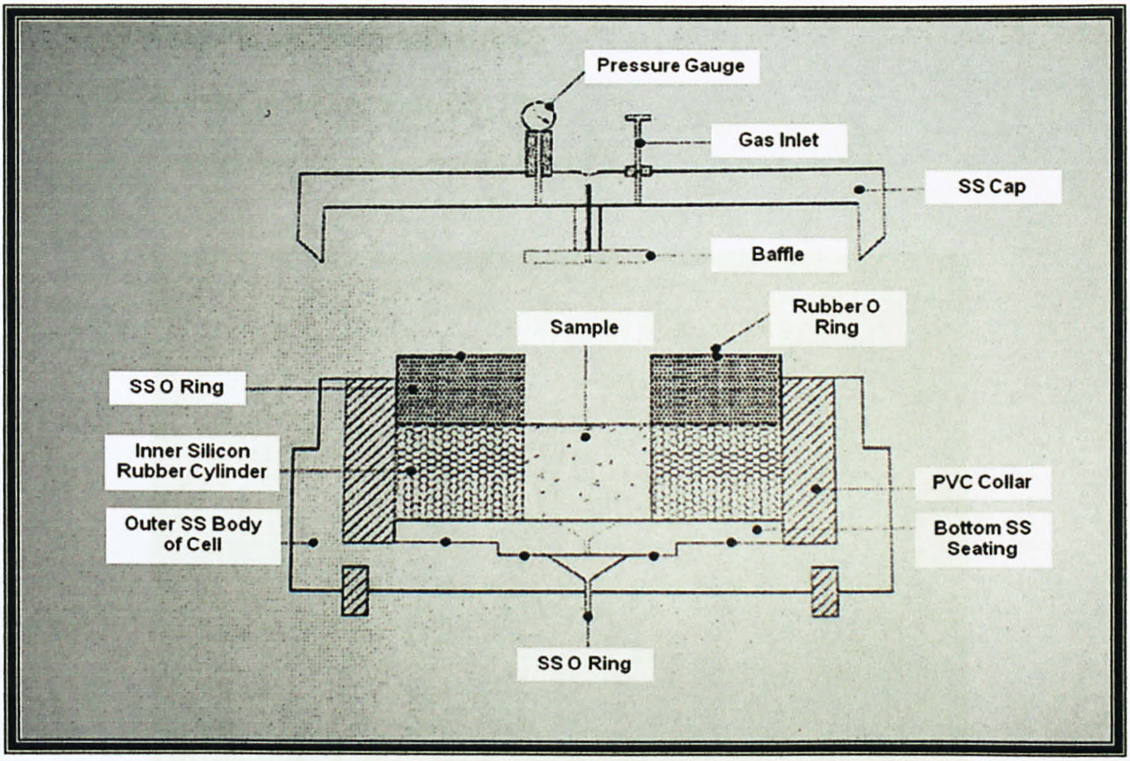

***Figure 2.6** : Schematic Diagram of the UTP Permeability Cell*

When a compressible gas, such as oxygen is used, Darcy's equation should be modified by using the expression proposed by Grube and Lawrence, which calculates the volume of fluid at the average pressure within the specimen.

$$k = \frac{q\mu}{A} \cdot \frac{L}{\Delta P} \quad \Rightarrow \quad k = \frac{2P_2 q\mu L}{A\left(P_1^2 - P_2^2\right)} \qquad (2.3)$$

Darcy's Law Equation — *Grube & Lawrence Expression*

where

q = flow rate (cm^3/s)

A = cross sectional area of specimen (m^2)

μ = viscosity of fluid (Ns/m^2)

L = length of specimen (m)

P_1 = inlet or applied pressure (bar)

P_2 = outlet pressure, normally 1 bar

k = coefficient of gas permeability (m^2)

***Figure 2.7**: Permeameter*

2.4 Rutting

Wheel-Tracking Test

As mention earlier, rutting happens when a depression or groove is worn into a road. The Wheel tracking test (See **Figure 2.8**) is used to assess the resistance to rutting of asphaltic materials under conditions which simulate the effect of traffic. A loaded wheel tracks a sample under specified conditions of speed and temperature while the development of the rut is monitored continuously during the test. The rut resistance can be quantified as the rate of rutting during the test or the rut depth at the conclusion of the test. The wheel test has been used by many researchers for many years to quickly assess the behavior of bituminous mixtures under traffic loading since the test provides several advantages compared with other test. One of the advantages is that the test specimens can be slabs prepared in the laboratory or 20 cm diameter cores cut from the highway pavement, hence the lab results can be compared with the actual performance of the road structure.

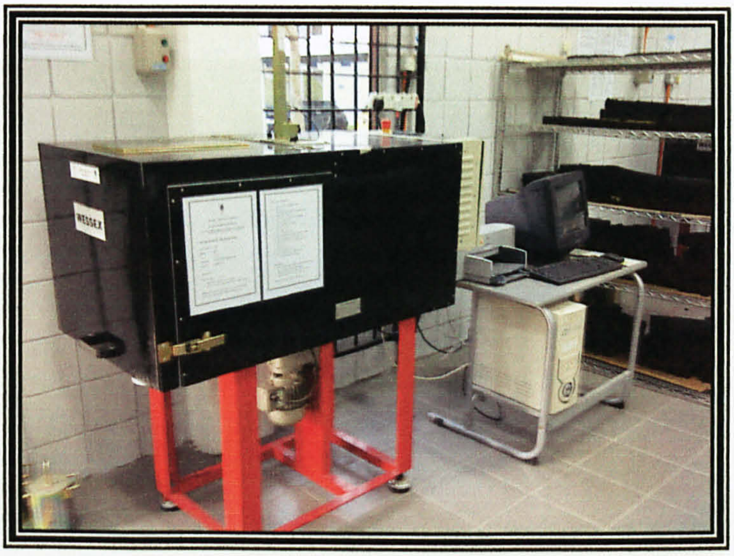

***Figure 2.8** : Wheel Tracking Machine*

2.5 Fatigue Cracking

Beam Fatigue Test (See **Figure 2.9**)

Under the influence of moving traffic loads, road pavements are subjected to continuous cyclic deformations during its lifetime. The dynamic character of the traffic load would cause the pavement to undergo various forms of distress. The processes of asphalt concrete deterioration under the cyclic loadings are determined by the fatigue properties of the material. Deformation and fatigue characteristics of the asphalt concrete in road pavements are due to the combined effect of the compressive, tensile and bending stresses caused by traffic and temperature variations.

The beam fatigue test was used to address the fatigue characteristics of the materials in the test. The test stress is determined by selecting a percentage (%) of the tensile strength of the test material and converting that value into a bending moment. Specimens tested at various loads provide data for plotting a Stress vs. Number of cycles (S/N) curve.

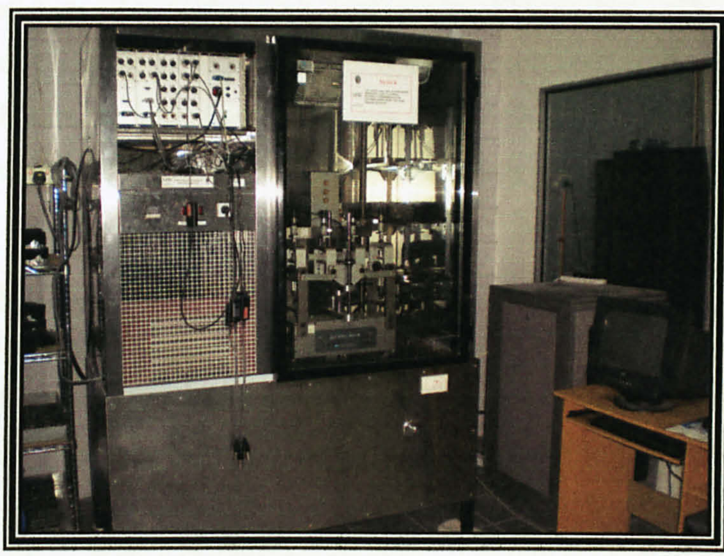

***Figure 2.9** : MATTA (Universal Asphalt Testing Machine)*

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 Procedure Identification

There are several methods/procedures that are carried out to ensure that the study will achieve its objectives. The process of the project flow is divided into two (2) parts (i.e : Final Year Project Part I & II). The accomplished phases are highlighted in this report.

Background Study

Elements of projects involved in this phase include the preliminary research; sources of references related to the topic were established. Using the UTP library access, approaches were done via Information Resource Centre (IRC) in the online resources and reference books on bituminous mixtures (See **Appendix A**). From the journals, some of the findings and data were summarized in which it will help in the study.

Seminars and Briefings

During the early stage of the course, there were a number of seminars and briefings in which will guide to further understand the way forward in this study. For example, the '*FYP (I) Workshop*', was held to further understand the method of referencing report writing. There was also a seminar held on Health, Safety, and Environment (HSE) issues for precaution during the project process.

Literature Survey and Research

The collection of all the available information and data via reference books and online resource will be done parallel to the laboratory works to strengthen the study. There will be a thorough revision on the finding and results obtained.

Material Preparation and Hazard Identification

Prior to the project work, the materials and equipments needed were prepared for future usage. All the highway materials and Personal Protection Equipment (P.P.E) were purchased at the hardware shop and the receipt (See **Appendix B**) was recorded for claim purposes.

For Health, Safety, and Environment (H.S.E) evaluations, a hazard identification check list of necessary safety precautions will be done. Other methods of identifying workplace hazards including analyzing the work processes and observation are also conducted through the whole stage of the study. Before the practical works are initiated, approach on the technician and lecturers will be expected for safety consultation. This is to ensure every necessary preparation is taken before proceeding. The detailed is discuss further in the next section.

Laboratory Works

Throughout the scope of project work, a thorough investigation will be implemented in the laboratory. In the preparation stage of the bituminous mixtures, a lot of experimental method is applied to verify the basic elements. For example, the characteristic tests of the bitumen and the aggregates. Whilst, as for the investigations for the rest of the study will be prolong at the second part of the course.

In the second part of the course, a lot of laboratory works were done to accomplish the objectives of the study. Continued from the previous part, the specific gravity of the materials involving coarse aggregates, bitumen, and fillers were determined. Also, the stage of preparing samples was started. Since there are two (2) types of gradations that is going to be employed, sieve analysis was carried out to obtain the combined gradation for coarse and fine aggregates, together with ordinary Portland cement. Lastly, in order to determine the optimum binder content for each variation of mixtures, Marshall mix design test was applied.

3.1.1 Determination of Bitumen Properties

A number of tests were employed in order to determine the basic properties of the bitumen used in this study.

Standard Penetration Test

The Standard Penetration Test (See **Figure 3.1**) is an empirical measurement of consistency (hardness) of the bitumen. In this test, a needle of specified dimensions is allowed to penetrate into a sample of bitumen, under a known load (100g), at a fixed temperature (25°C), for a known time (5 seconds). The penetration is given as the distance in units of 0.1 mm (or penetration unit) that the needle penetrates the sample. The test was conducted in accordance to BS 812 : Part 49 : 1983.

Ductility Test

The ductility test (See **Figure 3.2**) measures the distance a standard sample of asphaltic material will stretch out without breaking under a standard testing conditions (i.e : 50 mm per minute at 25°C). For the particular study, since bitumen of Grade 80 is used, the limiting ductility value at 25°C must not be less than 100 cm based on the Jabatan Kerja Raya (J.K.R) Standard. The test was conducted in accordance to BS 812.

Softening Point Test

The purpose of the Softening Point Test is to measure the susceptibility of the bitumen to temperature changes. In this test, a steel ball (3.5g) is placed on a sample of bitumen contained in a brass ring; this is suspended in water or glycerol bath. Water is used for bitumen with a softening point of 80°C or below, and glycerol is used for softening point greater than 80°C. The bath temperature is raised at 5°C per minute, the bitumen softens and eventually deforms slowly with the ball through the ring. At the moment the bitumen and steel ball touch the base plate 25mm below the ring, the temperature of the water is recorded. The test is performed in duplicate and the mean of the two measured temperatures is reported to the nearest 0.2°C for a penetration grade bitumen. If the difference between the two results exceeds 1.0°C the test must be repeated. The reported temperature is designated the softening point of the bitumen, and represent an equi-viscous temperature. According to the Jabatan Kerja Raya (J.K.R) Standard, the softening point limit for the bitumen of Grade 80 must not be less that 45°C and not more than 52°C. The test was conducted in accordance to BS 812.

Specific Gravity of Bitumen

The specific gravity of bitumen was determined using the pycnometer. It was firstly done filling a 600 ml Griffin low form beaker with distilled water. Next, the beaker was placed inside the water bath. Taking the weight of the pycnometer as Mass A, the pycnometer was filled with distilled water and placed in the beaker. Both of them were placed into the water bath. The weight of the pycnometer and water were then taken as Mass B. The sample inside the pycnometer was poured about 3/4 and be left to cool down. After that, the weight of the pycnometer and sample were recorded as Mass C. The pycnometer was filled with distilled water and placed into the beaker for 30 minutes. Later, the weight of the pycnometer was taken as Mass D. Calculations were made to determine the specific gravity. According to the Jabatan Kerja Raya (J.K.R) requirement, the limit of specific gravity for bitumen grade 80-100 is between 1.02-1.04.

3.1.2 Determination of Filler Properties

Specific Gravity of Fiiler

The filler used in this study was Ordinary Portland Cement (OPC). The specific gravity of the OPC was determined using the Ultrapycnometer (See Figure 3.3). The weight of the OPC to be tested was fed into the cell of the pycnometer and the specific gravity readings recorded electronically.

3.1.3 Determination of Aggregates Characteristics

The aggregates used in this study were granite and limestone. The characteristics of the aggregates used were determined in the laboratory through a number of tests.

Flakiness Index and Elongation Index (See Figure 3.4)

The flakiness index of an aggregate is defined as the percentage by mass of particles in a sample of single-sized aggregate whose least dimension (thickness) is less than 0.6 times their mean dimension. Meanwhile, the elongation index of an aggregate is defined as the percentage by mass of particles in a sample of single-sized aggregate whose greatest dimension (length) is more than 1.8 times the mean dimension of the two consecutive sieves. In order to separate the particles, gauges with pins set with appropriated gaps were used. The test was conducted in accordance to BS 812 : Part 105 : 1985.

Los Angeles Abrasion Test

The L.A Abrasion test (See Figure 3.5) has been developed with the purpose to evaluate the ease (or difficulty) with which aggregate particles are likely to wear under attrition from traffic loads. In this test, a sample of aggregate all retained on the No. 4 ASTM sieve are placed in a steel cylinder. 12 steel balls of 44-48 cm diameter were placed inside the cylinder fitted with an internal shelf and rotated at 30-33 rpm for 500 revolutions. The result of the test is expressed as the percentage by mass of material passing a No. 12 ASTM sieve (equivalent to a No.10 BS sieve) after the test. The Jabatan Kerja Raya (J.K.R) stated that the aggregate abrasion value (AAV) should not be more than 60% for all construction projects under their preview. The test was conducted in accordance to BS 812 : Part 113 : 1990.

Particle Density (Specific Gravity) & Water Absorption (See Figure 3.6)

The specific gravity of asphaltic materials is used mainly to determine the weight of a given volume of material, or vice versa, to determine the amount of voids in the compacted mixes. Specific gravity is defined as the ratio of the weight of a given volume of the material to the weight of the same volume of water. Determination of specific gravity for fine aggregates (i.e : sand) and coarse aggregates (i.e : granite and limestone) were carried out in the laboratory.

Sieve Analysis (See Figure 3.7)

The purpose of conducting the sieve analysis is to determine the combined aggregates gradation. Since there are two (2) types of gradation that were proposed in the study which are the gap-graded and well-graded gradation, the coarse and fine aggregates and filler were screened and combined to meet the grading curves. Based on the gradation limits from Jabatan Kerja Raya (J.K.R) manual and British Standards, the percentage of coarse and fine aggregates and filler were determined. The specification limits for the well-graded material are shown in ***Table 3.1*** in accordance to the J.K.R specifications. The specification limits for the gap-graded material are given in ***Table 3.2*** and is in accordance to the gap-graded gradation for Hot-Rolled Asphalt (HRA) wearing coarse as given in BS 594.

Table 3.1 : Well- Gradation Limit based on J.K.R pavement design manual

Seive size (mm)	Specification	
	Lower	Upper
20.0	76	100
14.0	64	89
10.0	56	81
5.0	46	71
3.35	32	58
1.18	20	42
0.425	12	28
0.150	6	16
0.075	4	8

Table 3.2 : Gap-Gradation Limit for HRA wearing coarse

Seive size (mm)	Specification	
	Lower	Upper
20.0	100	100
14.0	85	100
10.0	60	90
2.36	60	72
0.600	45	72
0.212	15	50
0.075	8	12

3.1.4 Bituminous Mixtures Properties

Marshall Mix Design Test

The original concepts of the method were developed by Bruce Marshall, and the test is now standardized and described in detail in ASTM Designation D1559 (Garber, 2002). A range of asphalt contents within the prescribed limit were prepared as the test specimens for the Marshall method. In this particular study, the specified range of asphalt contents were 4.5%-6.5% for the well-graded mix and 6.0%-8.0% for the gap-graded mix. 0.5% increments in the bitumen content were used in determining the optimum values from the Marshall tests was determined.

With the appropriate amount of aggregates and asphalt, the specimen is prepared by thoroughly mixing and compacting each of the mixture. The compactive effort used in this method is 75 blows of hammer falling a distance of 18 inch applied on both face of the sample. The specimens are then cooled and tested for stability (See Figure 3.8) and flow after determining its bulk density. In the stability test, the specimens are initially immersed in the water bath at a temperature of 60 degrees ^{0}C for a period of 30 to 40 minutes. The analysis of results form the Marshall test will be compared with the Jabatan Kerja Raya (J.K.R) manual as shown.

***Table 3.3** : J.K.R Requirement for Marshall Mix Design*

Parameter	Wearing Course	Binder Course
Stability	> 500 kg	> 450 kg
Flow	> 2.0 mm	> 2.0 mm
Porosity	3% - 5%	3% - 5%

3.1.5 Porosity Test

The porosity test was done according to the Marshall Mix Design test where the specimen preparation is similar to the procedure involved. When the specimens have been prepared and cooled down to room temperature, they are extruded from the moulds and the porosity test is ready for implementation. The specimens were weighted in air and water (See **Figure 3.9**) for density calculations. The result of each variation mixtures are compared with J.K.R requirements and further analyze.

3.1.6 Air Permeability Test

The permeability test is conducted using KENCO UTP pneumatic concrete Permeameter. This pneumatic apparatus is designed and used for the determination of air permeability. The PVC collar is placed inside the cell with the bottom stainless steel acting as the base. A specimen was then placed into the inner silicon rubber cylinder and installed together into the cell. Air trapped between the silicon rubber cylinder will be removed by suction trough a pipe fixed to the middle of the mould.

The cell cap is tightened and the inlet tubing is connected to the cell (See **Figure 3.10**). With all the outlets and flow meter control valves remain closed, the direct supply line is turned on. The pressure is increased gradually and no leakage is ensured. The flow meter is turned on and the flow rates are recorded once a steady state of flow has been reached (approx. 10 minutes). The flow rate is taken with reference to the reading corresponding to the center of the floating ball.

3.1.7 Performance Analysis

Wheel Tracking Test

Wheel tracking tests (See **Figure 3.11**) determine plastic deformation of asphalt based road surface wearing courses under temperature and pressures similar to those experienced under road use. Such tests are carried out during road construction and also in material design. The use of wheel tracking tests will prevent road surfaces being laid, which rut in hot weather and which need to be relayed. The equipment is housed in an insulated heated cabinet. Before testing, the machine is allowed to warm up without a sample present at the required testing temperature for approximately two (2) hours. A sample travels horizontally on a reciprocating table under a loaded wheel. Penetration of the wheel produces a rut, the depth of which is measured and recorded by a purpose built computer program.

Beam Fatigue Test

The Beam Fatigue Test was done by initially placing the beam sample in the MATTA machine (See **Figure 3.12**) for 1 hour under the temperature of 20°C. Prior to that, the measurements of the sample were taken which are the width and height at 3 points for average. Next, the sample is set up to the Beam Fatigue Apparatus and the necessary data is input to the computer. The pressure applied in the test was maintained in the range of 800 psi to 1000 psi.

<u>Observation & Record Results/Findings</u>

Along with the laboratory works, every results and findings were recorded immediately after the procedure. All the data were then tabulated and the changes in the values were observed carefully. The value of each data was recorded at least to the nearest three two decimal points and taken the average out of the trials made. From the findings gathered, graphs were plotted if necessary.

Calculations

Based on the results obtained, calculations process was initiated. Using the formulae for each experiment, the final values were determined in order to analyze the data in the next stage. For example, the Marshall Mix Test, using the lab results, the values for specific gravity, air voids, corrected stability, etc. was calculated. Some of the calculations were done manually, and most of it was calculated using the Microsoft Excel. The calculations are viewed in the chapter 4 of the report in results and discussion.

Analyze Data

The results were then analyzed and discussed to ensure that the laboratory works were done correctly. All the findings were compared to the standard specifications and checked so that it would not exceed the limit. The standard manual used are the Jabatan Kerja Raya (J.K.R) manual and British Standards. The discussion of the results was also included for further explanations.

3.2 Health Safety and Environment (HSE)

Before initiating the laboratory or practical works, hazards identification were implemented to ensure safety throughout the study. The necessary approaches taken were (1) developing a hazard check list (See **Appendix C**), (2) analyzing work processes and (3) observation were established. From the observation stage, it can be seen that for every equipment used in the lab, there were standard operating procedure that have to be followed as guidelines during the operation (See **Appendix D**). Furthermore, several tests prepared must be conducted in the presence of the technician. The hazard identification exercise should result in a list of hazard sources, the particular form in which hazard can occur, the areas of workplace or work process where it occurs and the potential persons exposed to that hazard.

3.3 Tools (See Appendix E)

The following are the tools that were used in the study :

i. Asphalt Mixer
ii. Coring Machine
iii. Electronic Buoyancy Balance
iv. Grease
v. Gyratory Testing Machine
vi. Hand Compactor
vii. L.A Abrasion Machine
viii. Marshall Compactor
ix. Marshall Testing Machine
x. Marshall Testing Machine
xi. Metal Length Gauge
xii. Metal Thickness Gauge
xiii. Oven
xiv. Permeameter
xv. Pycnometer
xvi. Rock Cutter
xvii. Sieve Shaker
xviii. Ultrapycnometer 1000
xix. Universal Testing Machine (MATTA)
xx. Vernier Caliper
xxi. Water Bath
xxii. WESSEX Wheel Tracker (S867)

Figure 3.1 *: Standard Penetration Test*

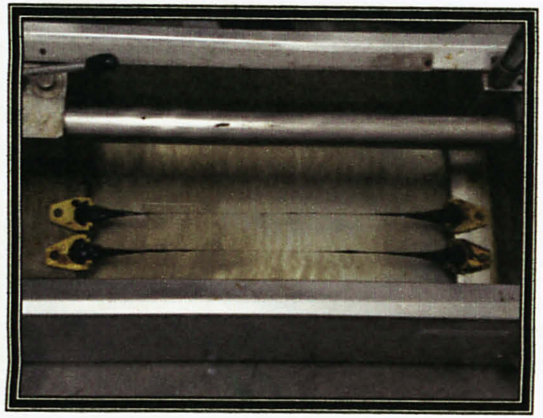

Figure 3.2 *: Ductility Test*

Figure 3.3 *: Ultrapycnometer 1000*

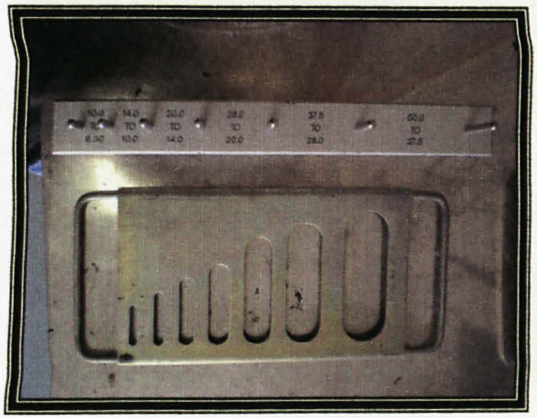

Figure 3.4 *: Metal Thickness and Length Gauge*

Figure 3.5 *: LA Abrasion Machine*

Figure 3.6 *: Pycnometer*

***Figure 3.7** : Sieve Shaker*

***Figure 3.8** : Marshall Stability Machine*

***Figure 3.9** : Porosity Test*

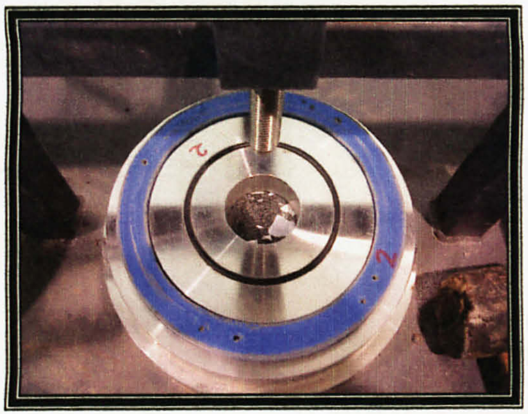

***Figure 3.10** : Air Permeability Test*

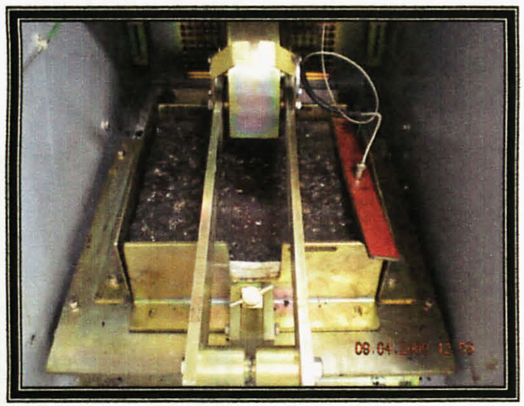

***Figure 3.11** : Wheel Tracking Machine*

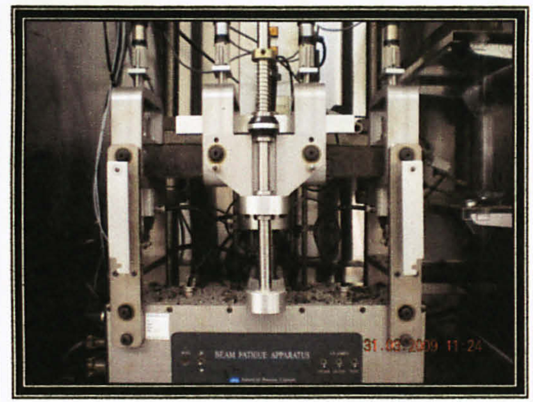

***Figure 3.12** : Beam Fatigue Apparatus*

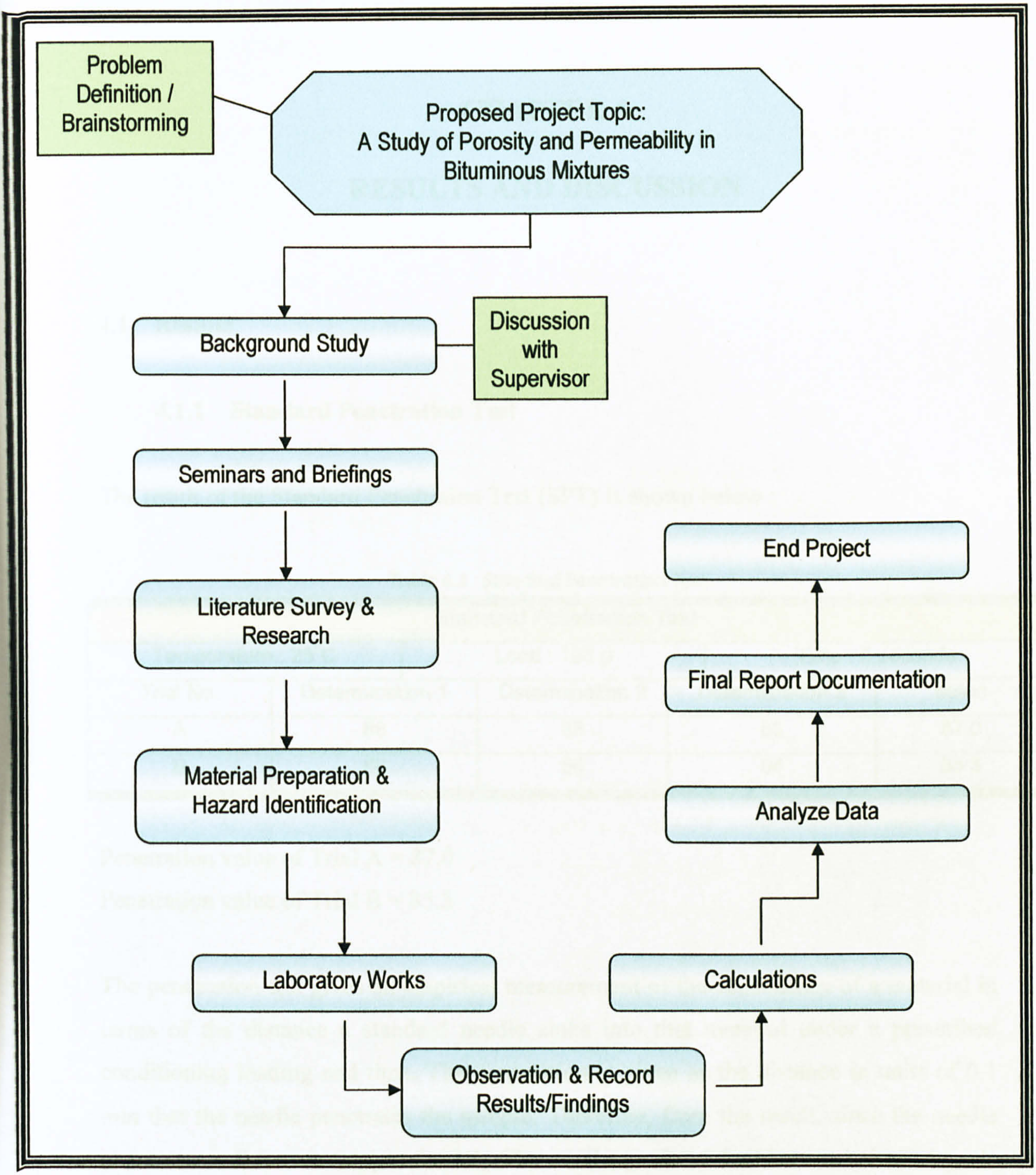

***Figure 3.13**: Project Flow Chart*

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Standard Penetration Test

The result of the Standard Penetration Test (SPT) is shown below :

***Table 4.1** : Standard Penetration Test*

Standard Penetration Test				
Temperature : $25^{o}C$	Load : 100 g		Time : 5 seconds	
Trial No.	Determination 1	Determination 2	Determination 3	Mean
A	88	88	85	87.0
B	86	86	84	85.3

Penetration value of Trial A = 87.0
Penetration value of Trial B = 85.3

The penetration test gives an empirical measurement of the consistency of a material in terms of the distance a standard needle sinks into that material under a prescribed conditioning loading and time. The penetration is given as the distance in units of 0.1 mm that the needle penetrates the sample. Therefore, from the result, since the needle penetrates a distance of approximately 80 mm, the grade of the bitumen is in fact grade 80.

Penetration	0-49	50-149	150-249	>250
Maximum difference between highest and lowest determination	2	4	6	8

From the test, the maximum difference between highest and lowest determination of penetration which is in the range of 50-149 and does not exceeds 4.

4.1.2 Ductility Test

The result of the ductility test is shown as below :

***Table 4.2** : Ductility Test*

Ductility Test				
Sample	Mould No. 1	Mould No. 2	Mould No.3	Mean
A (Grade 80)	104.0cm	111.2cm	121.3 cm	112.17 cm

Ductility value of Sample A = 112.17 cm

Ductility is necessary in bitumen as in practice, bituminous roads are subjected to both temperature change and traffic induced movement. The ductility factor depends on the quality of the bitumen. The bitumen specimen was stretched and the bitumen thread kept getting thinner and thinner to such a degree that it started to sag under its own weight until the thread was in contact with the metal bottom of the ductilometer bath. The adjustable water bath helps keep the temperature uniform at all points surrounding the specimen. According to the Jabatan Kerja Raya (J.K.R) Standard, the ductility value at 25°C must not be less than 100 cm. The average length of the bitumen specimen was 112.17 cm.

4.1.3 Ring and Ball Test (Softening Point)

The result of the softening point test is shown below :

***Table 4.3** : Softening Point Test*

Softening Point Test			
Trial	Ball 1 (°C)	Ball 2 (°C)	Mean(°C)
A (Grade 80)	48.0	48.6	48.3
B (Grade 80)	47.0	47.8	47.4

Average softening point value of Trial A = 48.3°C

Average softening point value of Trial B = 47.4°C

Referring to the Jabatan Kerja Raya (J.K.R) Standard, the softening point limit for the bitumen of Grade 80 must not be less that 45°C and not more than 52°C. The results obtained from two trials were 48.3°C and 47.4°C. This shows that both trials were within the J.K.R standard limits. During the experiment, the difference between the duplicate tests must not exceed 1.0°C.

4.1.4 Specific Gravity of Bitumen

***Table 4.4** : Results of Specific Gravity for Bitumen**

			Test No.	
			1	2
Mass of pycnometer and stopper,	A	(g)	19.0	19.4
Mass of pycnometer filled with water,	B	(g)	45.3	44.8
Mass of pycnometer filled with bitumen,	C	(g)	31.0	31.5
Mass of pycnometer filled with asphalt and water,	D	(g)	45.6	45.1
Relative Density			1.026	1.025

**Source: The Effect of Different Aggregate Types and Gradation on the Characteristics of Bituminous Mixtures*

$$relativeDensity = \frac{(C-A)}{[(B-A)-(D-C)]} \tag{4.1}$$

$$Density = Specific\ gravity \times W_T$$

$$where\ ,\ W_T = density\ of\ water\ at\ the\ test\ temperature$$

Referring to the Jabatan Kerja Raya (J.K.R) requirement, the limit of specific gravity for bitumen grade 80-100 is between 1.02-1.04. The average value of specific gravity for bitumen is 1.03 which is within the limitation.

4.1.5 Specific Gravity of Filler

The filler which is Ordinary Portland Cement (OPC) was tested to determine its density (specific gravity). The sample was initially weighted before testing. The results of the test run are shown in *Table 4.5*.

Specified weight = 3.78 gram

***Table 4.5** : Test Run for OPC**

Test Run	Volume (cm^3)	Density ($g/\ cm^3$)
1	1.14	3.32
2	1.14	3.31
3	1.13	3.34
4	1.13	3.33
5	1.14	3.33
6	1.14	3.31
Average	1.14	3.32

**Source: The Effect of Different Aggregate Types and Gradation on the Characteristics of Bituminous Mixtures*

From the observation of the results, the average value of specific gravity of Ordinary Portland Cement (OPC) is 3.32 as shown in *Table 4.5*.

4.1.6 Flakiness & Elongation Index

Granite

Table 4.6 : Result of Flakiness Index for Granite

Flakiness Index					
Size Fraction	Square Mesh Grading		Mass of fraction to be tested, M_2 (g)	Flakiness Gauge	
	Mass Retained (g)	Percent Passing (%)		Mass retained by gauge (g)	Mass passing gauge (g)
28.0 – 20.0	96	4.84	- (discarded)	- (discarded)	- (discarded)
20.0 – 14.0	1102	55.63	1102	1013	89
14.0 – 10.0	607	30.64	607	564	43
10.0 – 6.30	176	8.88	176	160	16
Total Masses, M_1 (g)	1981	100	$\Sigma M_2 = 1885$	1737	$\Sigma M_3 = 148$

$$FlakinessIndex = \frac{\Sigma M_3}{\Sigma M_2} x100\% \tag{4.2}$$

$$= \frac{148}{1885} x100\%$$

$$= 7.85\%$$

From the results obtained, the flakiness index for granite was calculated to be 7.85%. The mass from size fraction 28.0-20.0mm was discarded since the percentage passing was less than 5%. According to the Jabatan Kerja Raya (J.K.R) specifications, the value should not be more than 30%, thus it is within the requirement.

Table 4.7: Result of Elongation Index for Granite

Elongation Index					
Size Fraction	Square Mesh Grading		Mass of fraction to be tested, M_2 (g)	Elongation Gauge	
	Mass Retained (g)	Percent Passing (%)		Mass retained by gauge (g)	Mass passing gauge (g)
28.0 – 20.0	96	4.84	- (discarded)	- (discarded)	- (discarded)
20.0 – 14.0	1102	55.63	1102	203	899
14.0 – 10.0	607	30.64	607	156	451
10.0 – 6.30	176	8.88	176	77	99
Total Masses, M_1 (g)	1981	100	ΣM_2 = 1885	ΣM_3 =436	1449

$$ElongationIndex = \frac{\Sigma M_3}{\Sigma M_2} x100\% \quad (4.3)$$

$$= \frac{436}{1885} x100\%$$

$$= 23.1\%$$

Limestone

Table 4.8: Result of Flakiness Index for Limestone

Flakiness Index					
Size Fraction	Square Mesh Grading		Mass of fraction to be tested, M_2 (g)	Flakiness Gauge	
	Mass Retained (g)	Percent Passing (%)		Mass retained by gauge (g)	Mass passing gauge (g)
28.0 – 20.0	57	2.85	- (discarded)	- (discarded)	- (discarded)
20.0 – 14.0	1315	65.75	1315	1134	181
14.0 – 10.0	628	31.4	628	587	41
10.0 – 6.30	0	0	- (discarded)	- (discarded)	- (discarded)
Total Masses, M_1 (g)	2000	100	ΣM_2 = 1943	1721	ΣM_3 =222

$$FlakinessIndex = \frac{\Sigma M_3}{\Sigma M_2} x100\%$$

$$= \frac{222}{1943} x100\%$$

$$= 11.4\%$$

From the results obtained, the flakiness index for limestone was calculated to be 11.4%. The mass from size fraction 28.0-20.0mm and 10.0-6.30mm were discarded since the percentage passing was less than 5%. According to the Jabatan Kerja Raya (J.K.R) specifications, the value should not be more than 30%, thus it is within the requirement.

***Table 4.9**: Result of Elongation Index for Limestone*

Elongation Index					
Size Fraction	Square Mesh Grading		Mass of fraction to be tested, M_2 (g)	Elongation Gauge	
	Mass Retained (g)	Percent Passing (%)		Mass retained by gauge (g)	Mass passing gauge (g)
28.0 – 20.0	57	2.85	- (discarded)	- (discarded)	- (discarded)
20.0 – 14.0	1315	65.75	1315	117	1198
14.0 – 10.0	628	31.4	628	295	333
10.0 – 6.30	0	0	- (discarded)	- (discarded)	- (discarded)
Total Masses, M_1 (g)	2000	100	ΣM_2 = 1943	ΣM_3 =412	1531

$$ElongationIndex = \frac{\Sigma M_3}{\Sigma M_2} x100\%$$

$$= \frac{412}{1943} x100\%$$

$$= 21.2\%$$

4.1.7 Aggregate Abrasion Test

Granite

Table 4.10: LA Abrasion Test for Granite

Los Angeles Abrasion Test					
			Test No.		
			1	2	Mean
Mass of aggregate retained on No.4 ASTM sieve	M_1	(kg)	5	5	
Mass of material passing No.12 ASTM sieve	M_2	(kg)	1.261	1.252	
Los Angeles abrasion value	$\frac{M_2}{M_1} \times 100\%$		25.2%	25.0%	25.1%

Limestones

Table 4.11: LA Abrasion Test for Limestone

Los Angeles Abrasion Test					
			Test No.		
			1	2	Mean
Mass of aggregate retained on No.4 ASTM sieve	M_1	(kg)	5	5	
Mass of material passing No.12 ASTM sieve	M_2	(kg)	1.304	1.312	
Los Angeles abrasion value	$\frac{M_2}{M_1} \times 100\%$		26.08%	26.24%	26.2%

As we can see from the results, the average aggregate abrasion value (AAV) for granite is 25.1% whilst that for limestone is 26.2%. Both AAV were not more that 60% which was the requirement based on the Jabatan Kerja Raya (J.K.R) specifications.

4.1.8 Particle Density (Specific Gravity) & Water Absorption

Sand

Table 4.12 : Particle Density (Specific Gravity) & Water Absorption for Sand

			Test No.	
			1	2
Mass of saturated surface-dry sample in air	A	(g)	497	494
Mass of vessel containing sample and filled with water	B	(g)	1860	1856
Mass of vessel filled with water only	C	(g)	1557	1555
Mass of oven-dry sample in air	D	(g)	495.0	491.1

Calculation :

		Test No.		
		1	2	Average
Particle density on an oven-dried basis	$\frac{D}{A-(B-C)}$	2.55	2.54	2.545
Particle density on a saturated and surface-dried basis	$\frac{A}{A-(B-C)}$	2.56	2.56	2.560
Apparent particle density	$\frac{D}{D-(B-C)}$	2.58	2.58	2.580
Water Absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.4%	0.6%	0.5%

The experiment is conducted to measure the particle density and absorption of aggregates (in this case sand only). The results show that the average particle density on an oven-dried basis is 2.545. Apparent particle density is 2.580 and the water absorption is 0.5% of the dry mass. The particle density or Specific Density of the aggregates (sand) that is obtained from the experiment is 2.56.

Granite

Table 4.13 : Particle Density (Specific Gravity) & Water Absorption for Granite

			Test No.	
			1	2
Mass of saturated surface-dry sample in air	A	(g)	984	1065
Mass of vessel containing sample and filled with water	B	(g)	2170	2212
Mass of vessel filled with water only	C	(g)	1556	1562
Mass of oven-dry sample in air	D	(g)	977	1055

Calculation :

		Test No.		
		1	2	Average
Particle density on an oven-dried basis	$\frac{D}{A-(B-C)}$	2.64	2.54	2.59
Particle density on a saturated and surface-dried basis	$\frac{A}{A-(B-C)}$	2.66	2.57	2.62
Apparent particle density	$\frac{D}{D-(B-C)}$	2.69	2.60	2.65
Water Absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.72%	0.95%	0.84%

The experiment is conducted to measure the particle density and absorption of aggregates (in this case Granite). The results show that the average particle density on an oven-dried basis is 2.59. Apparent particle density is 2.65 and the water absorption is 0.84% of dry mass. The particle density or Specific Density of the aggregates (Granite) obtained from the experiment is 2.62.

Limestone

Table 4.14 *: Particle Density (Specific Gravity) & Water Absorption for Limestone*

			Test No.	
			1	2
Mass of saturated surface-dry sample in air	A	(g)	1035	1079
Mass of vessel containing sample and filled with water	B	(g)	2213	2243
Mass of vessel filled with water only	C	(g)	1559	1562
Mass of oven-dry sample in air	D	(g)	1020	1056

Calculation :

		Test No.		
		1	2	Average
Particle density on an oven-dried basis	$\frac{D}{A-(B-C)}$	2.68	2.65	2.67
Particle density on a saturated and surface-dried basis	$\frac{A}{A-(B-C)}$	2.72	2.71	2.72
Apparent particle density	$\frac{D}{D-(B-C)}$	2.79	2.82	2.81
Water Absorption (% of dry mass)	$\frac{100(A-D)}{D}$	1.47%	2.18%	1.83%

The experiment is conducted to measure the particle density and absorption of aggregates (in this case Limestone). The results show that the average particle density on an oven-dried basis is 2.67. Apparent particle density is 2.81 and the water absorption is 0.5% of dry mass. The particle density or Specific Density of the aggregates (Limestone) that is obtained from the experiment is 2.72.

4.1.9 Sieve Analysis

Well-Graded Gradation

Table 4.15 *: Aggregates Blending Calculation for Well-Graded Gradation*

Sieve Size (mm)	Cum. Passing (%)			Cum. Passing (%)			Combined Cum. Passing	Spec. Limit
	Coarse	Sand	Filler	*(42%)* Coarse	*(50%)* Sand	*(8%)* Filler		
28	100	100	100	42.00	50.00	8.00	100	100
20	100	100	100	42.00	50.00	8.00	100	76 - 100
14	56.60	100	100	23.77	50.00	8.00	81.77	64 - 89
10	22.95	100	100	9.64	50.00	8.00	67.64	56 - 81
5	12.07	100	100	5.07	50.00	8.00	63.07	46 - 71
3.35	0	98.20	100	0.00	49.10	8.00	57.10	32 - 58
1.180	0	65.13	100	0.00	32.57	8.00	40.57	20 - 42
0.425	0	30.96	100	0.00	15.48	8.00	23.48	12 - 28
0.150	0	0.018	100	0.00	0.01	8.00	8.01	6 - 16
0.075	0	0.025	80	0.00	0.01	6.40	6.41	4 - 8

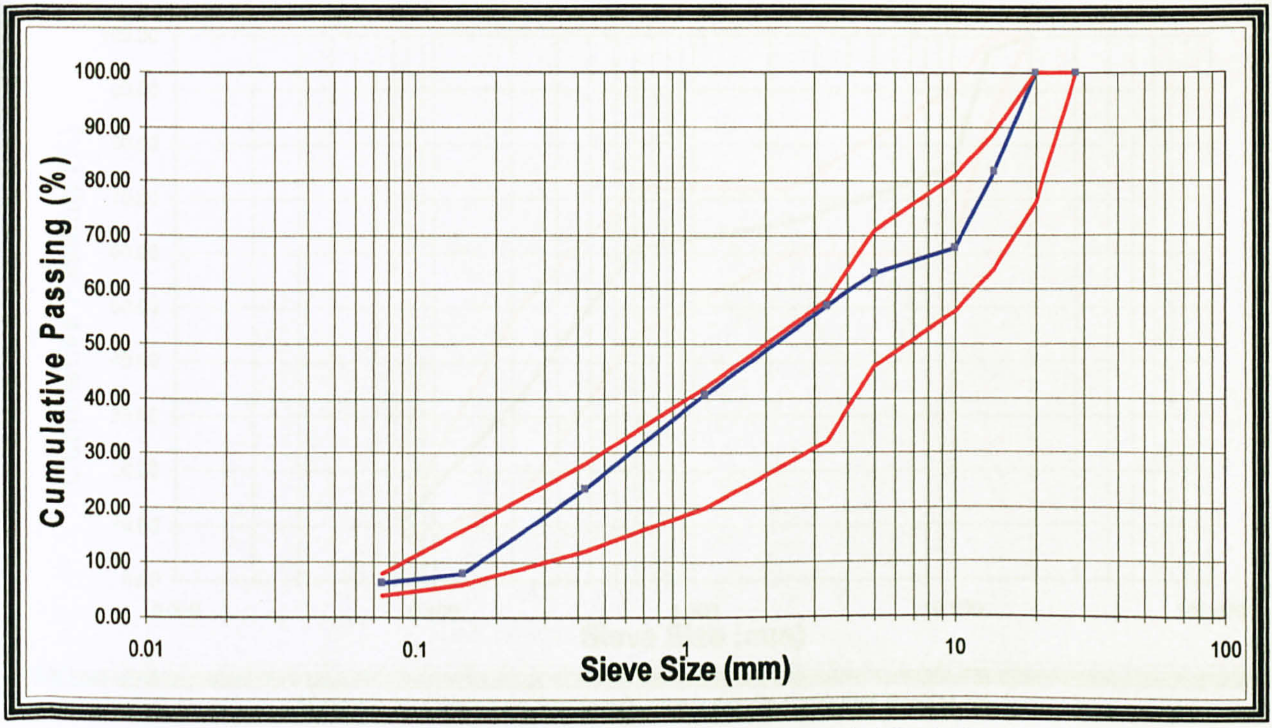

Figure 4.1 *: Combined Gradation Curve for Well-Graded Gradation*

From the combined gradation curves for well-graded gradation, we can see that the line satisfy within the specification limit. The faction of mix for gap-graded gradation is 42% for coarse aggregates, 50% for fine aggregates, and 8% for filler.

<u>Gap-Graded Gradation</u>

***Table 4.16** : Aggregates Blending Calculation for Gap-Graded Gradation**

Sieve Size (mm)	Cum. Passing (%)			Cum. Passing (%)			Combined Cum. Passing	Spec. Limit
	Coarse	Sand	Filler	*(33%)* Coarse	*(57%)* Sand	*(10%)* Filler		
20.000	100	100	100	33	57	10	100.00	100
14.000	91.8	100	100	30.29	57	10	97.29	85 - 100
10.000	27.12	100	100	8.95	57	10	75.95	60 - 90
2.360	0	97.66	100	0	55.67	10	65.67	60 - 72
0.600	0	89.36	100	0	50.94	10	60.94	45 - 72
0.212	0	40.96	100	0	23.35	10	33.35	15 - 50
0.075	0	1.3	100	0	0.74	10	10.741	8 - 12

**Source: Stability and Tensile Strength of Bituminous Mixtures*

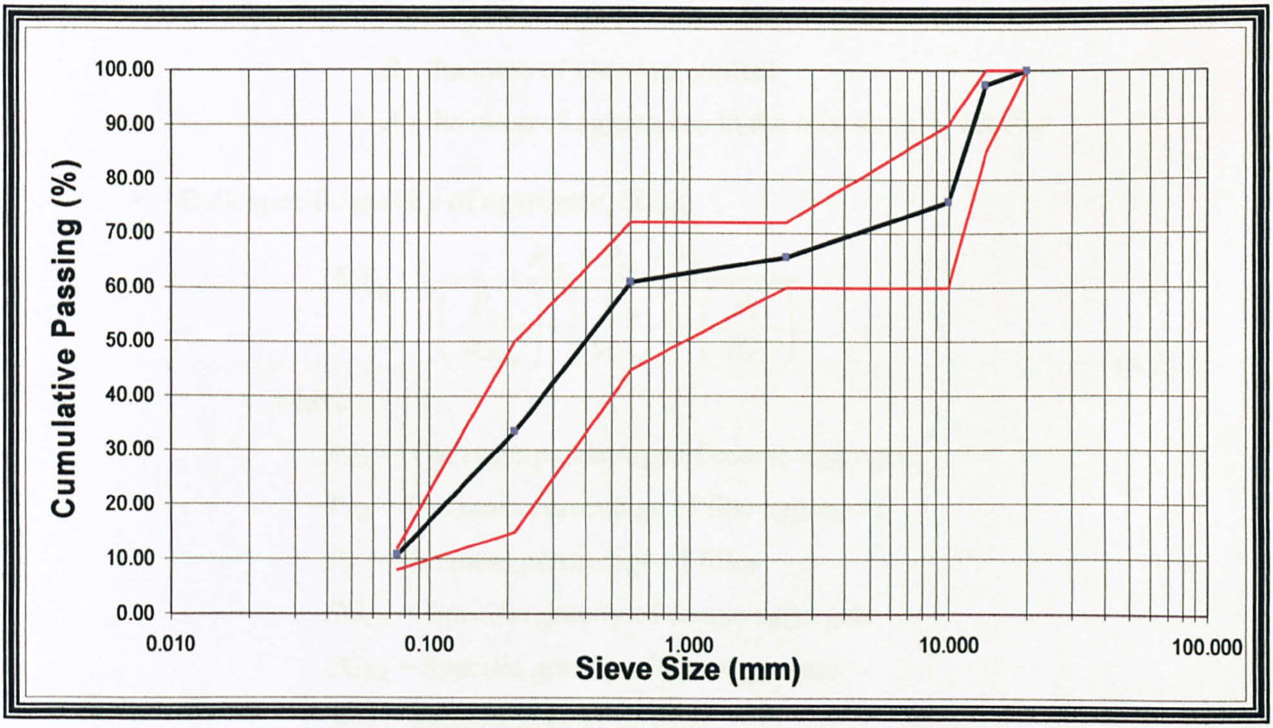

***Figure 4.2** : Combined Gradation Curve for Gap-Graded Gradation*

From the combined gradation curves for gap-graded gradation, we can see that the line satisfy within the specification limit. The faction of mix for gap-graded gradation is 33% for coarse aggregates, 57% for fine aggregates, and 10% for filler.

4.1.10 Marshall Mix Design Test

The Marshall mix design were performed on the mixture to obtain the optimum binder content that will provide the required stability, durability, and other additional properties such as impermeability, workability, and resistance to bleeding.

The initial calculations were carried out as follows :

- Mass of bitumen content :

$$n\% = \frac{B_{n\%}}{B_{n\%} + A} \tag{4.4}$$

Thus;

$$B_{n\%} = \frac{nA}{1-n}$$

where ;

n : the percentage of bitumen in the mix sample

B : the mass of bitumen content

A : the mass of aggregates in the mix sample, *1200kg*

- Bulk specific gravity of aggregate, SG_{agg} :

$$SG_{agg} = \frac{P_{CA} + P_{FA} + P_F}{\left(\frac{P_{CA}}{SG_{CA}}\right) + \left(\frac{P_{FA}}{SG_{FA}}\right) + \left(\frac{P_F}{SG_F}\right)} \tag{4.5}$$

where ;

P_{CA} = The mass percentage of coarse aggregate

P_{FA} = The mass percentage of fine aggregate

P_F = The mass percentage of filler

SG_{CA} = Specific gravity of coarse aggregate

SG_{FA} = Specific gravity of fine aggregate

SG_F = Specific gravity of filler

Well-Graded Granite

Table 4.17 : Marshall Test Data for Well-Graded Granite

Binder Content by Mass of Mix (%)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)
	Bulk (*Density*)	Max.	VMA	Porosity		
4.5	2.359	2.462	14.485	4.180	1.43	5.070
5.0	2.379	2.444	14.212	2.665	1.81	5.338
5.5	2.371	2.426	14.940	2.279	2.88	6.211
6.0	2.360	2.409	15.788	2.042	4.17	3.506
6.5	2.357	2.392	16.318	1.441	3.45	3.608

Gap-Graded Granite

Table 4.18 : Marshall Test Data for Gap-Graded Granite

Binder Content by Mass of Mix (%)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)
	Bulk (*Density*)	Max.	VMA	Porosity		
4.5	2.367	2.467	14.382	4.041	2.67	4.685
5.0	2.374	2.449	14.578	3.055	3.55	4.752
5.5	2.394	2.431	14.301	1.516	4.29	5.482
6.0	2.385	2.414	15.088	1.196	3.29	4.579
6.5	2.360	2.397	16.431	1.540	4.58	4.659

Well-Graded Limestone

Table 4.19 : Marshall Test Data for Well-Graded Limestone

Binder Content by Mass of Mix (%)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)
	Bulk (*Density*)	Max.	VMA	Porosity		
4.5	2.328	2.496	16.885	6.714	3.46	2.976
5.0	2.323	2.477	17.492	6.214	4.42	4.548
5.5	2.336	2.459	17.463	4.987	3.56	4.842
6.0	2.391	2.441	15.988	2.061	5.03	6.086
6.5	2.368	2.423	17.223	2.278	5.13	5.534

Gap-Graded Limestone

***Table 4.20** : Marshall Test Data for Gap-Graded Limestone*

Binder Content by Mass of Mix (%)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)
	Bulk (*Density*)	Max.	VMA	Porosity		
6.0	2.295	2.440	19.285	5.915	4.27	3.382
6.5	2.299	2.422	19.585	5.077	4.50	4.183
7.0	2.297	2.405	20.093	4.484	3.00	5.171
7.5	2.308	2.387	20.130	3.324	3.56	5.031
8.0	2.312	2.370	20.417	2.458	5.42	4.782

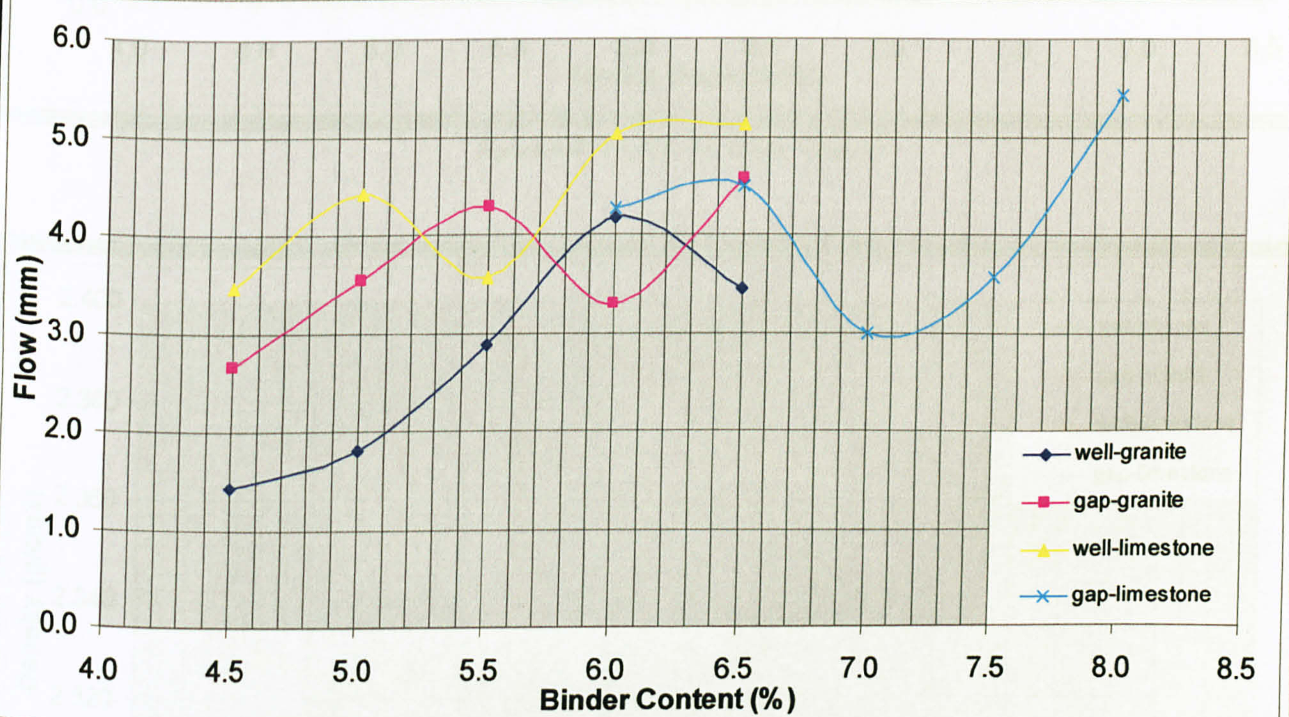

***Figure 4.3** : Flow vs. Binder Content*

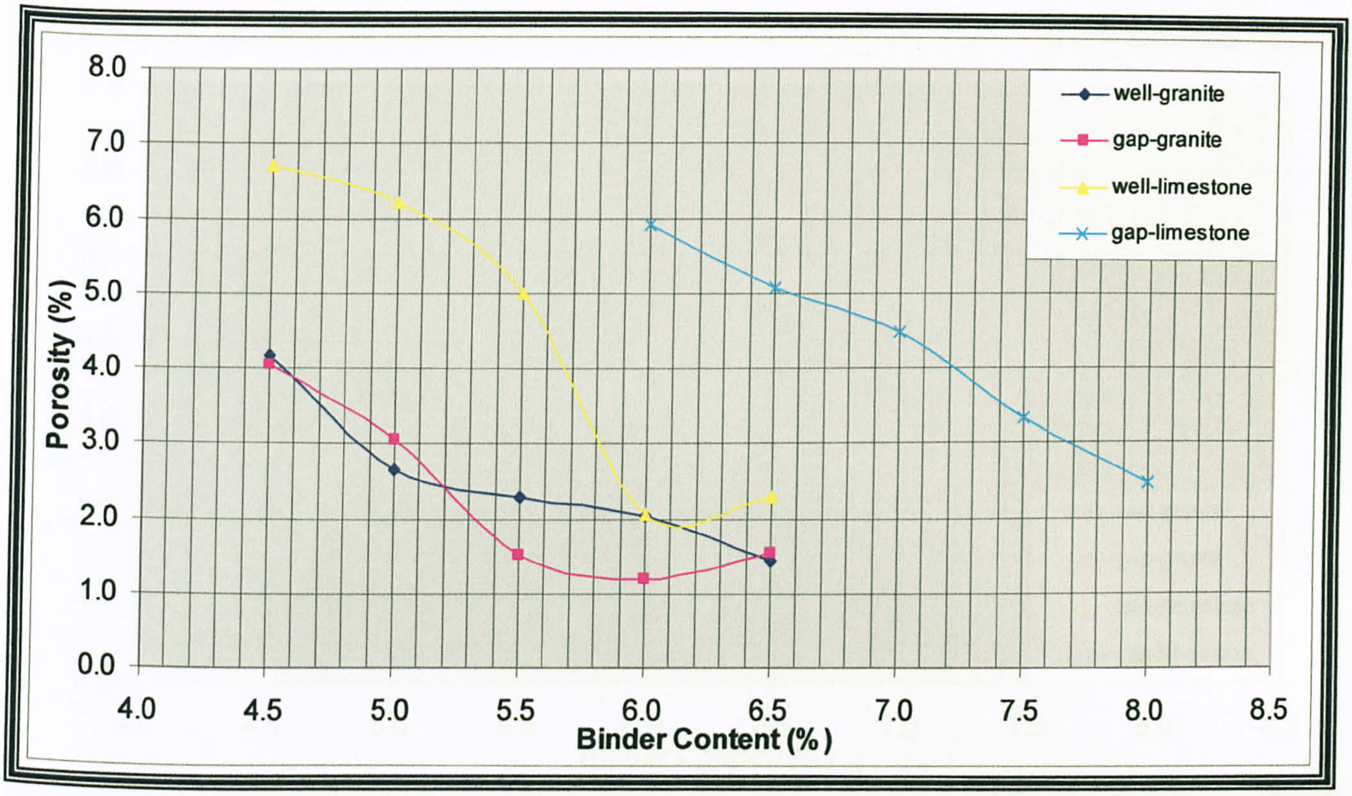

Figure 4.4 : Porosity vs. Binder Content

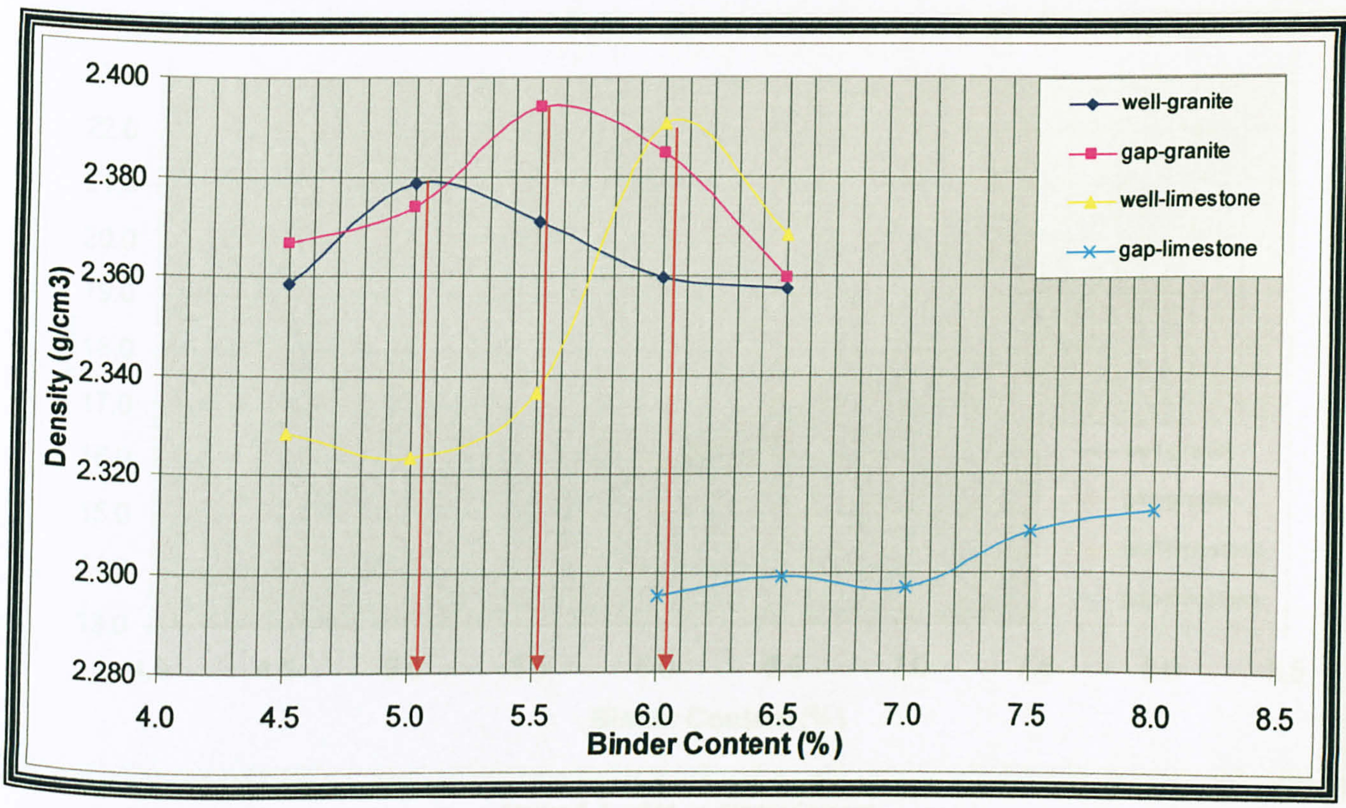

Figure 4.5 : Density vs. Binder Content

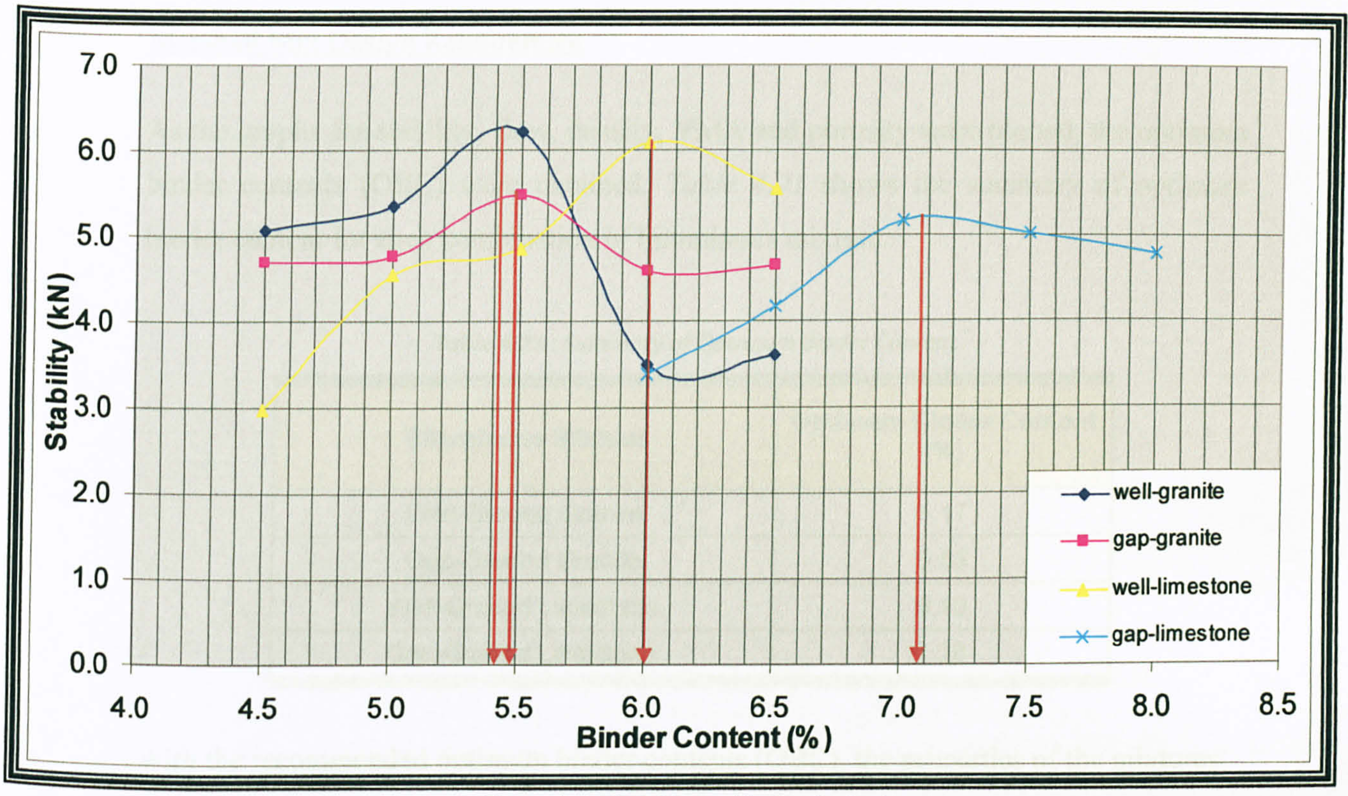

Figure 4.6 : Stability vs. Binder Content

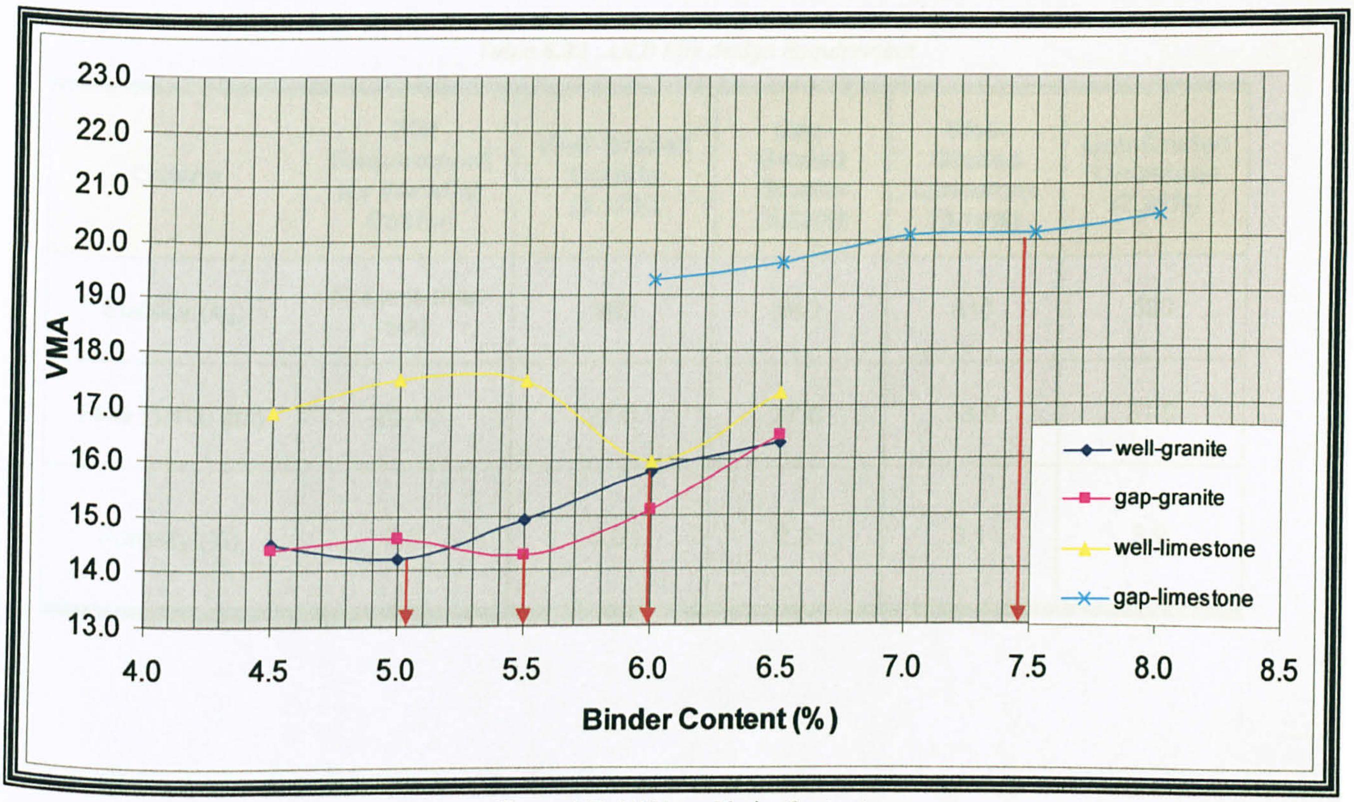

Figure 4.7 : VMA vs. Binder Content

Marshall Mix Design Requirement

As the graphs for stability, flow, density, VMA and porosity were plotted, the optimum binder contents (OBC) were obtained. *Table 4.21* shows the summary of optimum binder content for each combination of bituminous mixture.

Table 4.21 : Summary of Optimum Binder Content

Bituminous Mixture	Optimum Binder Content (%)
Well-Graded Granite	5.17
Gap-Graded Granite	5.53
Well-Graded Limestone	6.10
Gap-Graded Limestone	7.28

With the recommended optimum binder contents (OBC), the properties of the mixtures were compared with the mix design requirement by JKR.

Table 4.22 : J.K.R Mix design Requirement

Criteria	JKR Requirement for Wearing Coarse	Well-Graded Granite *(5.17%)*	Gap-Graded Granite *(5.53%)*	Well-Graded Limestone *(6.10%)*	Gap-Graded Limestone *(7.28%)*
Stability (kg)	Not less than 500	550	540	610	520
Flow (1/100 cm)	20-40	22.0	37.0	38.0	31.0
Porosity (%)	3-5	3.0	2.3	3.1	3.9

4.1.11 Porosity Test

As mention earlier, the porosity test was done using the Marshall Mix Design Method. The composition of each bituminous mixture and the optimum binder content were taken from the early justification.

Table 4.23 : Result of Porosity Test

Bituminous Mixtures	Binder Content by Mass of Mix (%)	Mass of Specimen		Volume (cm3)	Specific Gravity of Mix		Air Voids (%)	
		In Air (g)	In Water (g)		Bulk (Density)	Max	Agg (VMA)	Total Mix (Porosity)
A	B	C	D	E	F	G	H	I
Well-Graded Granite	5.17	1262.00	721.50	540.50	2.335	2.438	15.939	4.219
Gap-Graded Granite	5.53	1270.50	721.50	549.00	2.314	2.430	17.188	4.763
Well-Graded Limestone	6.10	1290.0	739.5	550.50	2.343	2.438	17.743	3.865
Gap-Graded Limestone	7.28	1306.0	738.0	568.00	2.299	2.395	20.243	3.992

where B = Optimum Binder Content (OBC)

C = measure weight for each specimen in air

D = measure weight for each specimen in water

E $= C - D$

$$F = \frac{C}{C - D}$$

$$G = \frac{100}{\dfrac{100 - B}{SG_{agg}} + \dfrac{B}{SG_{bit}}}$$

$$I = 100 - \frac{100 \times F}{G}$$

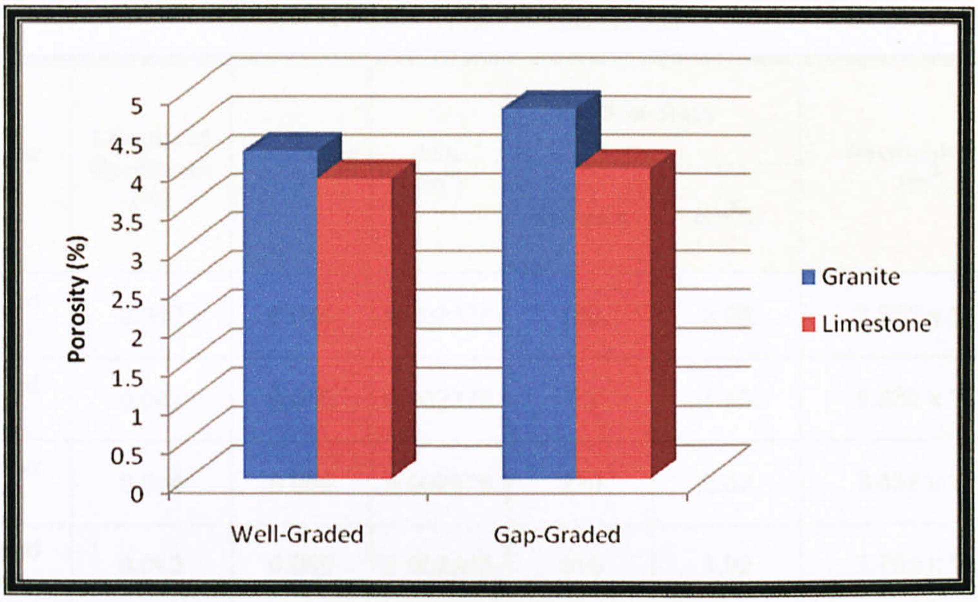

***Figure 4.8** : Porosity Chart*

In this particular investigation, the outcome shows that the porosity for Granite and Gap-graded gradation both exceeds that of Limestone and Well-Graded gradation respectively. From the earlier justification, it clearly showed that the Limestone used was denser than the Granite, so the higher porosity in Granite may be influenced by this factor. As for the gradation, the mixture of Well-Graded gradation has higher porosity as it contain lower composition of finer aggregates compared to Gap-Graded gradation.

4.1.12 Air Permeability Test

The result of the investigation was tabulated as shown in ***Table 4.24***.

Inlet or applied pressure = 3 bar/psi Oxygen

Outlet pressure = 1 bar/psi Oxygen

Viscosity of fluid (Oxygen) = 2.02 x 10^{-5} N.s/m^2

Table 4.24 : Result for Air Permeability Test

Bituminous Mixtures	Length of Specimen (m)	Diameter (m)	Area (m^2)	Flow Rate		Permeability (m^2)
				mL/min	cm^3/s	
Well-Graded Granite	0.040	0.055	0.002376	180	3.00	2.551×10^{-4}
Gap-Graded Granite	0.042	0.055	0.002376	90	1.50	1.339×10^{-4}
Well-Graded Limestone	0.044	0.055	0.002376	220	3.67	3.432×10^{-4}
Gap-Graded Limestone	0.043	0.055	0.002376	115	1.92	1.755×10^{-4}

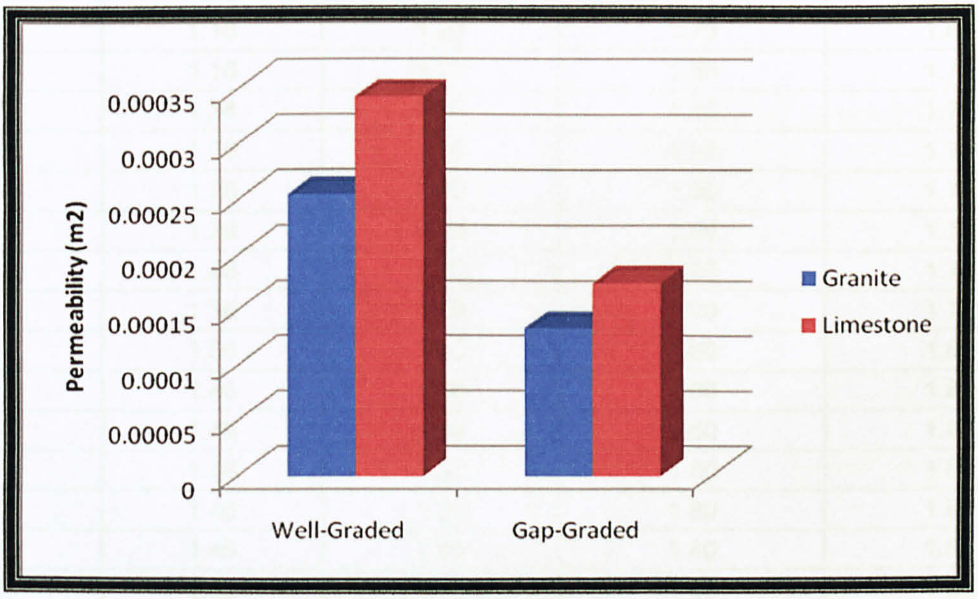

Figure 4.9 : Permeability Chart

From the observation of the results, the value of permeability is higher among the Well-Graded Gradation compared to Gap-Graded Gradation. In terms of types of aggregates, Granite is less permeable than Limestone.

4.1.13 Wheel Tracking Test

The wheel tracking test was carried out with the aim of measuring the resistance to deformation characteristics of bituminous mixtures subjected to traffic loading.

***Table 4.25** : Result for Wheel Tracking Test*

Time (minutes)	Depth (mm)			
	Well-Graded Granite	**Gap-Graded Granite**	**Well-Graded Limestone**	**Gap-Graded Limestone**
0	0.00	0.00	0.00	0.00
1	0.61	0.40	1.00	1.00
2	0.86	0.70	1.30	1.20
3	0.96	0.90	1.50	1.30
4	0.99	1.10	1.60	1.50
5	1.06	1.20	1.60	1.60
6	1.16	1.20	1.70	1.60
7	1.16	1.20	1.80	1.70
8	1.24	1.20	1.80	1.70
9	1.25	1.00	1.90	1.70
10	1.25	0.90	1.90	1.70
11	1.29	0.80	1.90	1.70
12	1.36	1.10	1.90	1.70
13	1.36	1.30	1.90	1.70
14	1.36	1.30	1.80	1.80
15	1.46	1.30	1.80	1.80
16	1.46	1.40	1.80	1.80
17	1.46	1.40	1.80	1.80
18	1.46	1.30	1.80	1.80
19	1.46	1.40	1.80	1.80
20	1.56	1.40	1.80	1.80
21	1.56	1.40	1.80	1.80
22	1.56	1.40	1.80	1.80
23	1.56	1.40	1.80	1.80
24	1.56	1.40	1.80	1.80
25	1.65	1.40	2.00	1.80
26	1.66	1.40	2.20	1.80
27	1.66	1.20	2.00	1.80
28	1.66	1.20	2.00	1.80
29	1.71	1.20	2.00	1.80

30	1.74	1.20	2.00	1.80
31	1.75	1.30	2.00	1.80
32	1.75	1.40	2.00	1.80
33	1.75	1.40	2.00	1.80
34	1.75	1.30	2.00	1.80
35	1.75	1.20	2.00	1.80
36	1.83	1.30	2.00	1.80
37	1.86	1.30	2.00	1.80
38	1.86	1.40	2.00	1.80
39	1.86	1.40	2.00	1.80
40	1.86	1.40	2.00	1.80
41	1.86	1.40	2.00	1.80
42	1.94	1.30	2.00	1.80
43	1.94	1.30	2.00	1.80
44	1.96	1.30	2.00	1.80
45	1.96	1.20	2.60	1.80
46	1.96	1.20	3.30	1.80

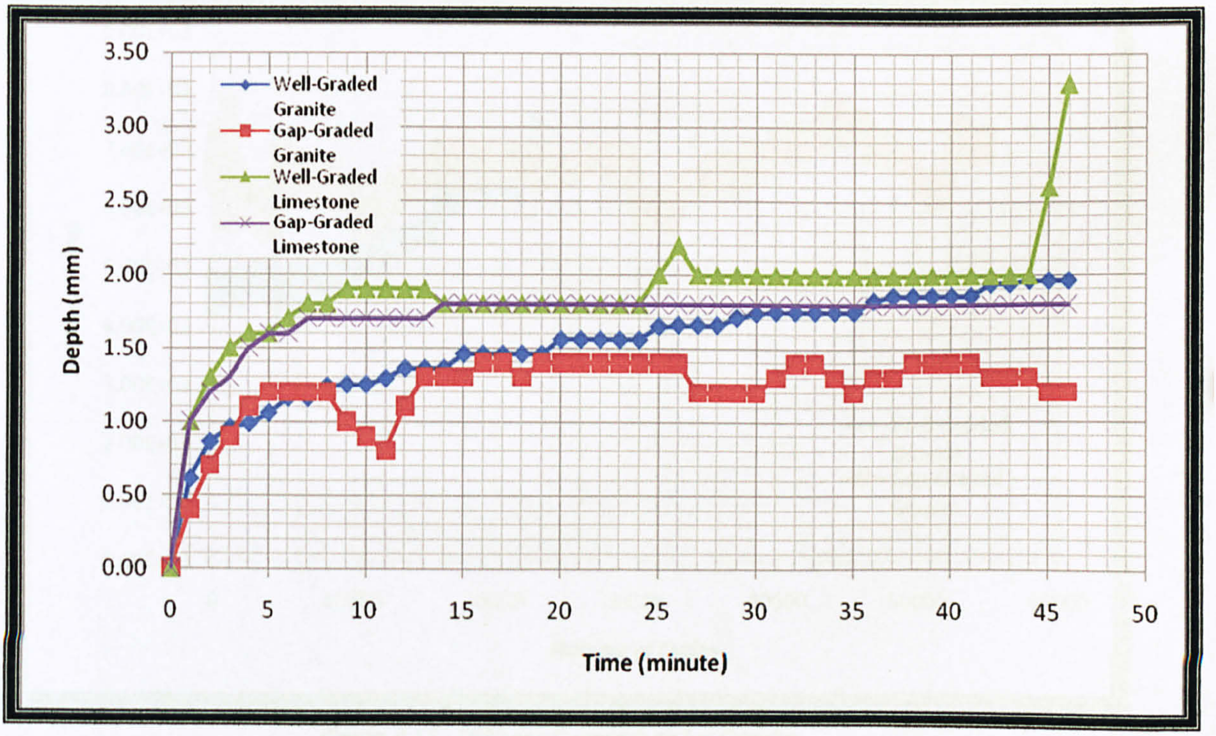

Figure 4.10 : Rut Depth Comparison

Figure 4.10 shows the comparison between the rut depths of the mixes tested. Gap-Graded Granite gave a better performance in the Wheel Tracking Test as exhibited by the lower rut depth. Based on the gradation, Gap-Graded gradation performed better for both Granite and Limestone compared to Well-Graded gradation. Meanwhile, for types of aggregate, it clearly shows that Granite has lower rut depth than Limestone in the Wheel Tracking Test.

4.1.14 Beam Fatigue Test

Two (2) tests were performed for each type of aggregate in the Beam Fatigue Test. The results are presented in the graph below :

<u>Granite</u>

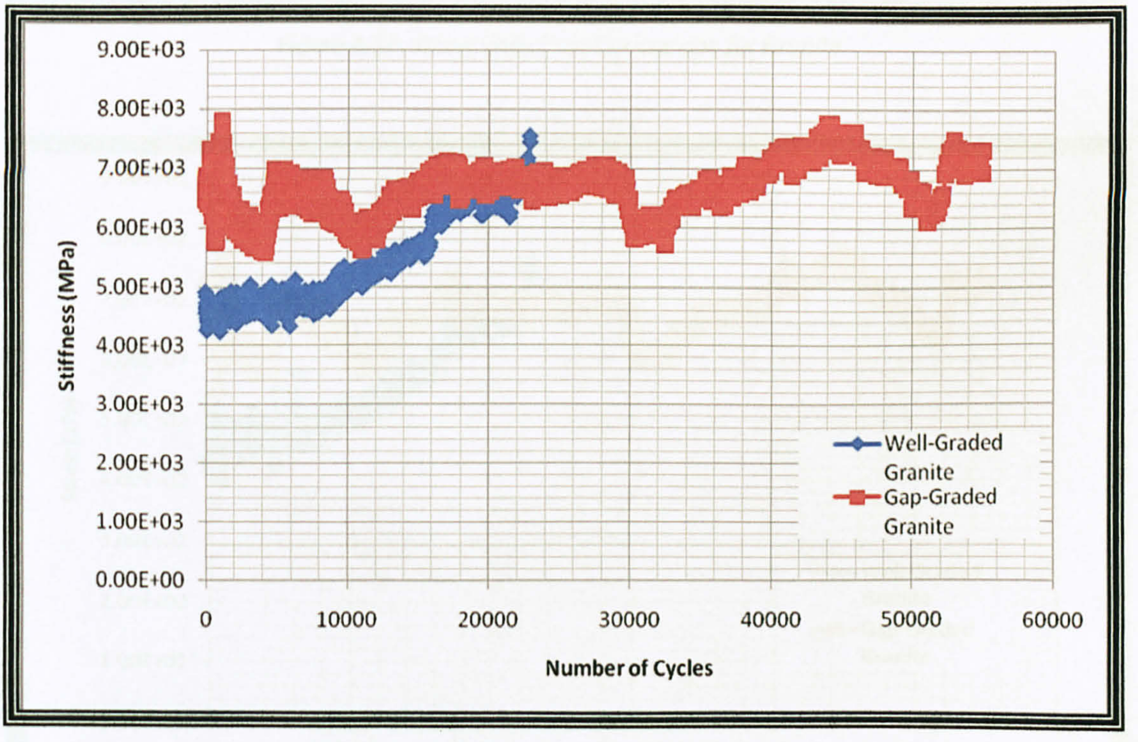

***Figure 4.11** : Stiffness Comparison for Granite*

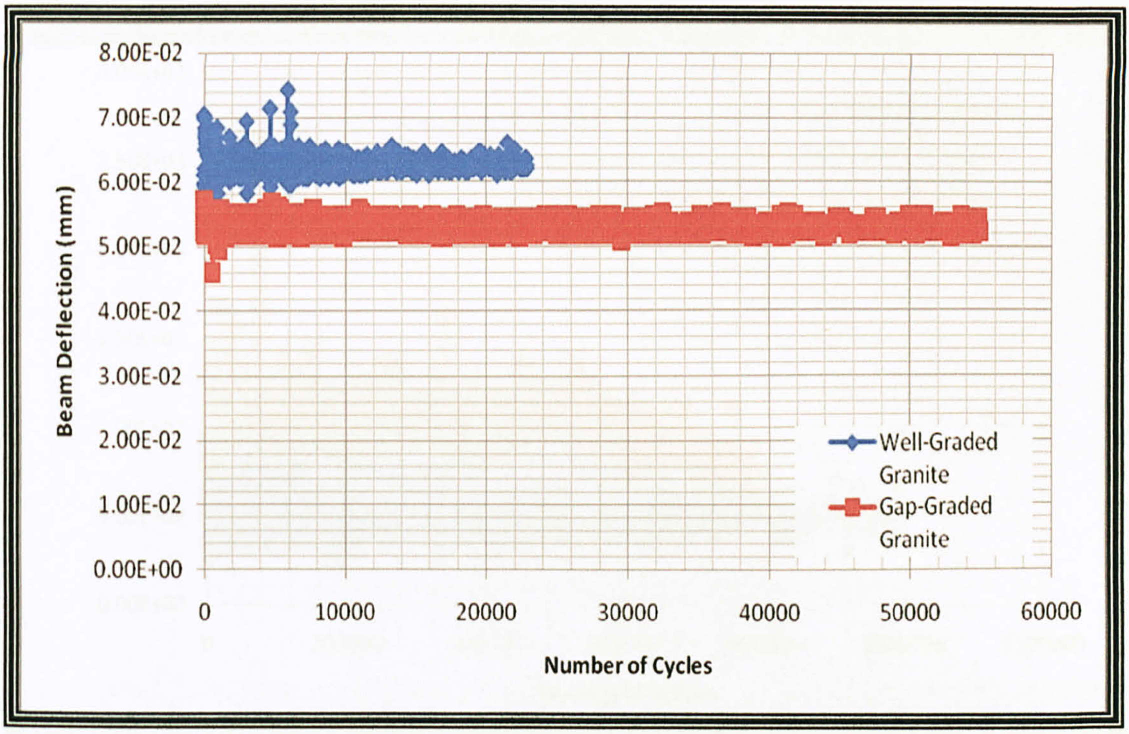

***Figure 4.12** : Beam Deflection Comparison for Granite*

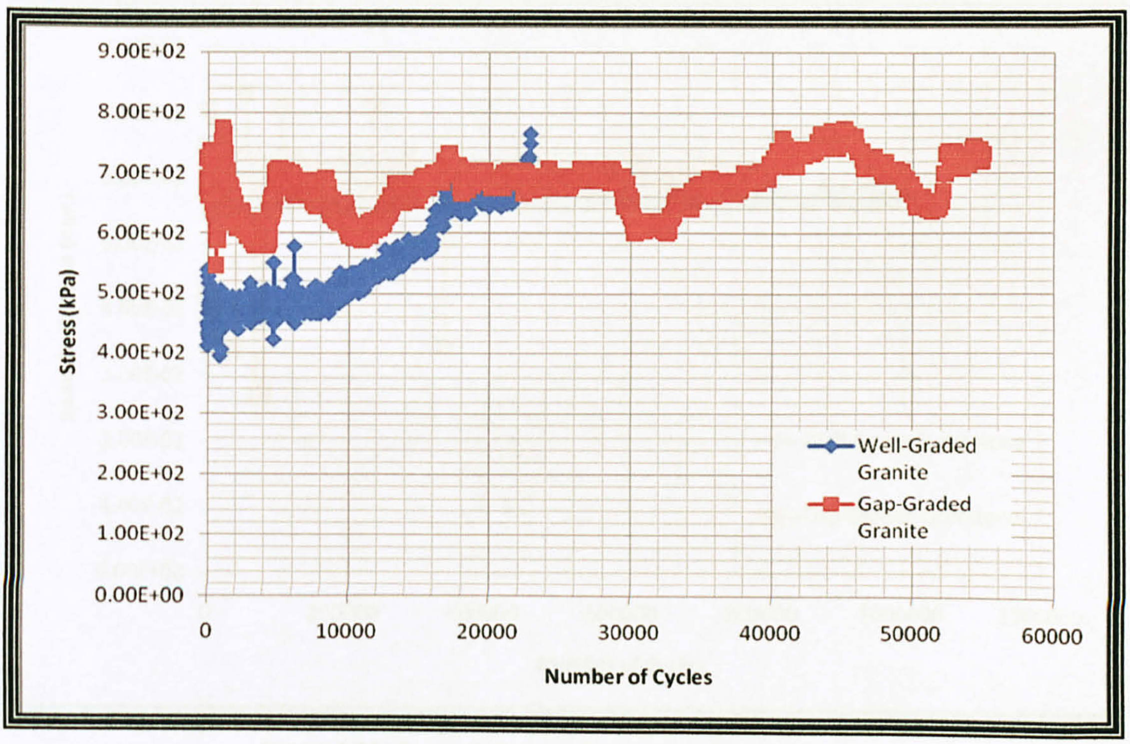

***Figure 4.13** : Stress Comparison for Granite*

Limestone

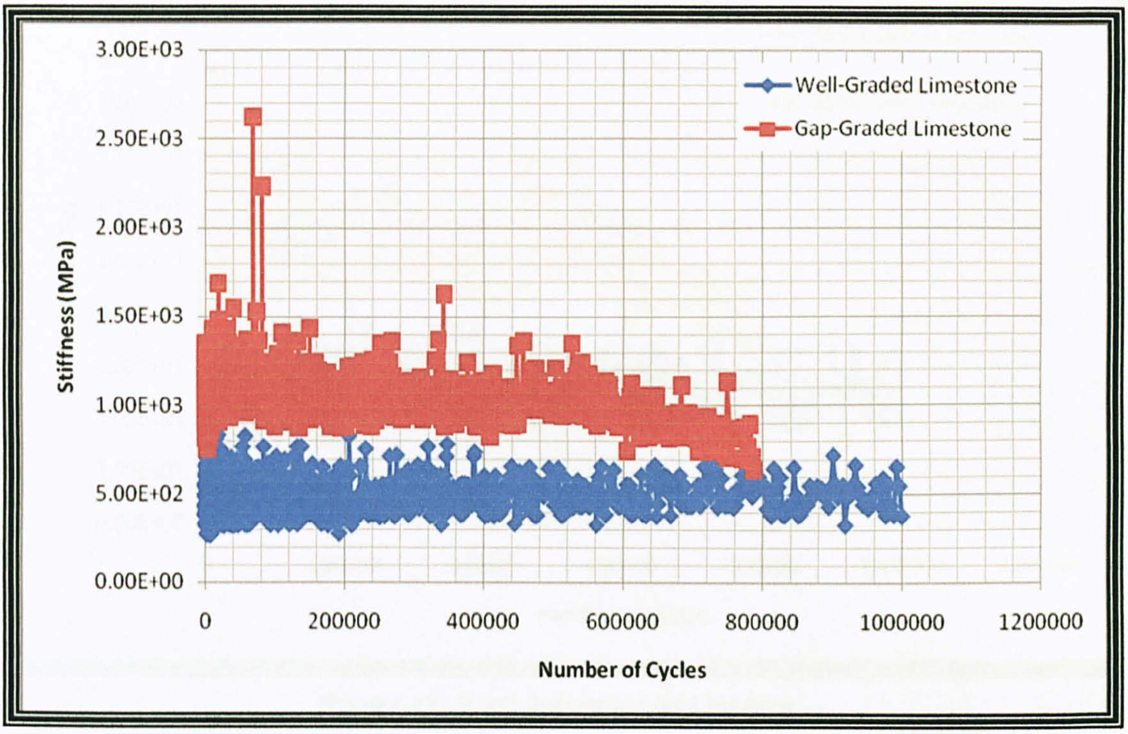

***Figure 4.14** : Stiffness Comparison for Limestone*

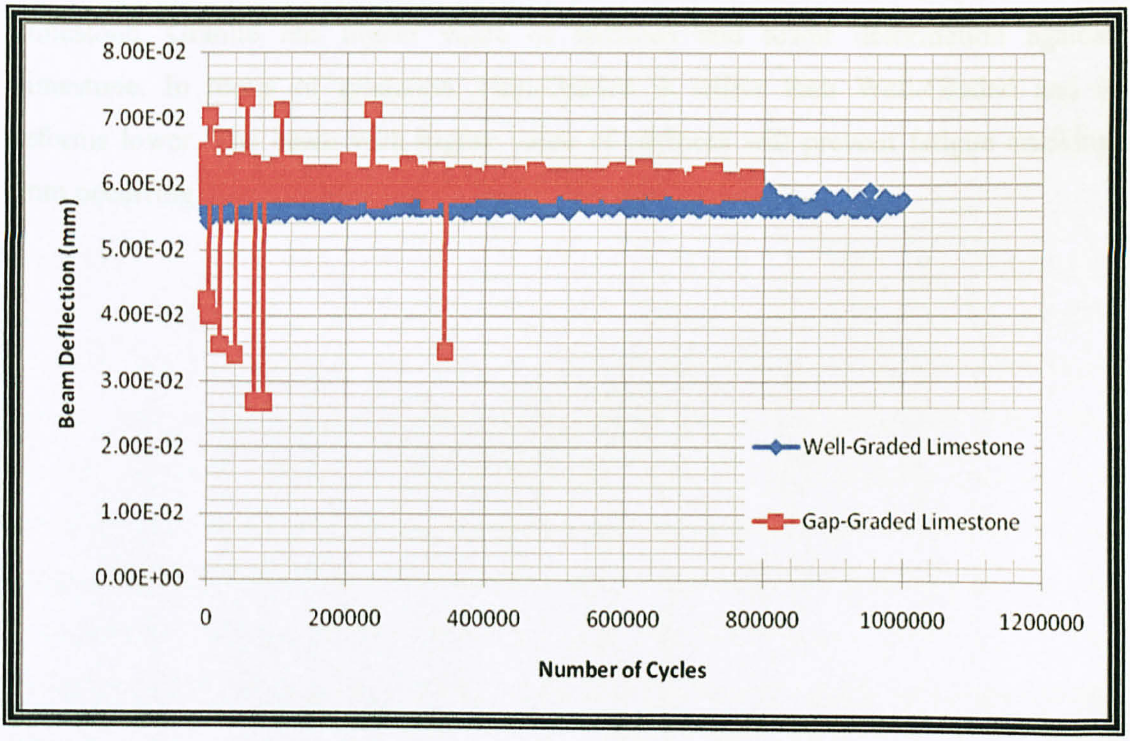

***Figure 4.15** : Beam Deflection Comparison for Limestone*

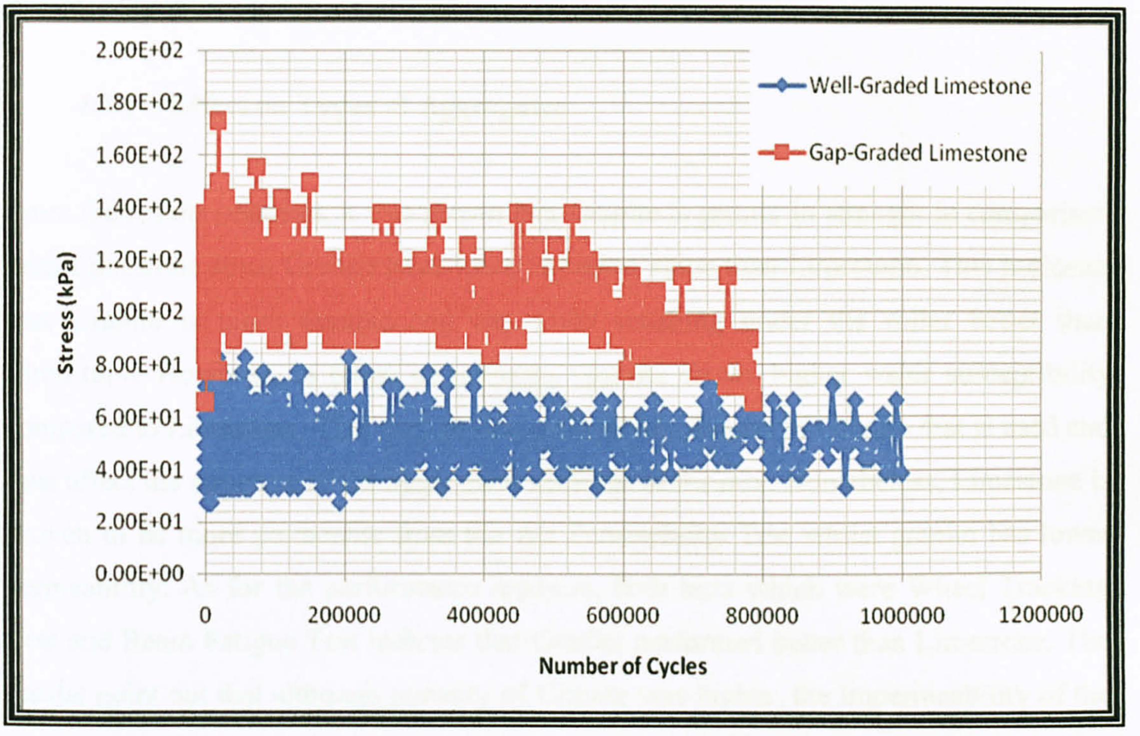

***Figure 4.15** : Stress Comparison for Limestone*

From the results obtained, Granite is less prone to fatigue cracking compared to Limestone. Granite has higher value of stiffness and lower deformation against Limestone. In terms of gradation, Gap-Graded is stiffer than Well-Graded and it deforms lower. The beam with higher value of stiffness will prevent fatigue cracking from occurring.

4.2 Discussion

4.2.1 Effect on Types of Aggregates

From the results obtained, it was shown that Granite is greater in strength in comparison with Limestone since Granite have lower abrasion value than Limestone. This indicates that Granite is more durable and can resist crushing under the roller better than Limestone. However, in terms of porosity, Granite shows higher water susceptibility compared to Limestone. This may be due to the lower density of Granite that is used and thus affect the structure of the aggregates skeleton in the mix. Nonetheless, Limestone is proven to be more permeable from the Air Permeability Test whilst granite has lower permeability. As for the performance analysis, both tests which were Wheel Tracking Test and Beam Fatigue Test indicate that Granite performed better than Limestone. The results point out that although porosity of Granite was higher, the impermeability of the aggregate will determine the best performance outcome. Hence, in order for the failure to occur, it is believe that the voids have to be connected.

4.2.2 Effect on Aggregate Gradation

As can be seen from the Marshall Mix Test, the value of stability for Well-Graded gradation both exceeds the Gap-Graded gradation for Granite and Limestone respectively. It might be reasonable to presume that the best gradation is the one that produces the maximum stability. This would involve a particle arrangement where smaller particles are packed between the larger particles, which reduce the void space between particles. Moreover, the porosity test further verified that the Well-Graded gradation have lower percentage of porosity compared to the Gap-Graded gradation. Despite the result of stability and porosity, the Air Permeability Test indicate that the Gap-Graded gradation is less permeable than the Well-Graded gradation and the performance analysis support the hypothesis that the impermeability determines better result for rutting and fatigue cracking. These findings does not justify that Well-Graded gradation is better that Gap-Graded gradation. It may be caused by certain errors that might take place along the process such as human errors or equipment errors. However, previous research has shown that Gap-Graded aggregates can produce mixtures with physical properties equal to or better than Well-Graded aggregates at usually higher optimum asphalt contents (Lee, 1971). Furthermore the analysis proved that permeability affects the performance of the bituminous mixtures and thus plays an important factor of the occurrence of failure.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Throughout the course of this project, it can be concluded that the objectives of the study was successfully achieved. The investigation of porosity and permeability was conducted on a variation of bituminous mixtures. The mixtures applied were a combination of Granite and Limestone for types of aggregates with Well-Graded and Gap-Graded for the aggregates gradation. Subsequently, the study was further expanded to develop a relationship on the performance of each bituminous mixture. From the experimental results, it proved that Granite with Gap-Graded gradation was a better highway material.

i. Granite has higher strength than Limestone since it has lower value Aggregate Abrasion Value (AAV) but Granite has higher water susceptibility compared to Limestone. In terms of permeability Limestone is more permeable than Granite
ii. Well-Graded gradation shows lower percentage of porosity than Gap-Graded gradation however it is high in permeability.
iii. The performance analysis (i.e : Wheel Tracking Test and Beam Fatigue Test) indicate that mixture with lower permeability perform better and discourage rutting and fatigue cracking. This is because in order for the failure to occur, the voids have to be connected.

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APPENDICES

i) Appendix A - Reference Book from Information Resource Centre

ii) Appendix B - Receipt from Hardware Shop

iii) Appendix C - Hazard Identification

iv) Appendix D - Examples of the Standard Operating Procedure

v) Appendix E - Images of the Tools

vi) Appendix F - Images of Laboratory Works

APPENDIX A

Reference Book from Information Resource Centre

Information Resource Centre
UNIVERSITI TEKNOLOGI PETRONAS

08/06/2008
11:37 am

Name:IDZMIL HAFFIZ B MOHAMMAD
Patron_ID:IT8759
Title:Bituminous binders and mixes : state of the art
and interlaboratory tests on mechanical behaviour an
Item ID:IPB200901
Due Date: 05-09-08

Title:Asphalt surfacings / by Asphalt Surfacings : a
guide to asphalt surfacings and treatments used for t
Item ID:IPB021069
Due Date: 05-09-08

Title:Porous Pavements / Bruce K Ferguson
Item ID:IPB188814
Due Date: 05-09-08

Title:Asphalt concrete : simulation, modeling, and
experimental characterization : proceedings of the R
Item ID:IPB187424
Due Date: 05-09-08

Title:Asphalt mix design and construction : past
present, and future sponsored by Construction
Institute
Item ID:IPB210362
Due Date: 05-09-08

Please Keep This Receipt

Thank you for using Information Resource Centre

APPENDIX B

Receipt from Hardware Shop

现沽單

CASH SALE

Dealers in Building Materials Mines Foundry & Estate Requisites

永發五金貿易

霹靂端洛大街門牌一號

霹靂端洛新市鎮大路門牌二及三號

ENG HUAT HARDWARE TRADING

No. 1, Main Road, 31750 Tronoh, Perak. Fax & Tel: 05-3676737
No. 2 & 3, Persiaran Desa Tronoh Indah, Desa Tronoh Indah, 31750 Tronoh, Perak. Tel: 05-3711436

專辦建筑材料膠圍
礦場用品銅鐵器皿
專營打彬油，天那
火酒，蠟油，黑油
膏及各種油類大小
五金各種塑膠用器

No. 241605

M/s. Cash

D/O No.

Address.

Date: 16-1-09

數量 Quantity		貨名 Particulars	價格 Price	銀額 Amount RM	sen
6 pc.		Sarung tangan.	1.00	6	00
2 pcs.		Dust mask.	2.50	5	00
3 set.		Sarung tangan kalis.	3.50	10	50
1 bag	3/4	Batu congkrit.		5	00
3 roll	1½	masking tape	1.80	5	40
			Rm	31	90
			~~Rm~~	~~26~~	~~50~~
			合計 TOTAL RM	~~26~~	~~50~~

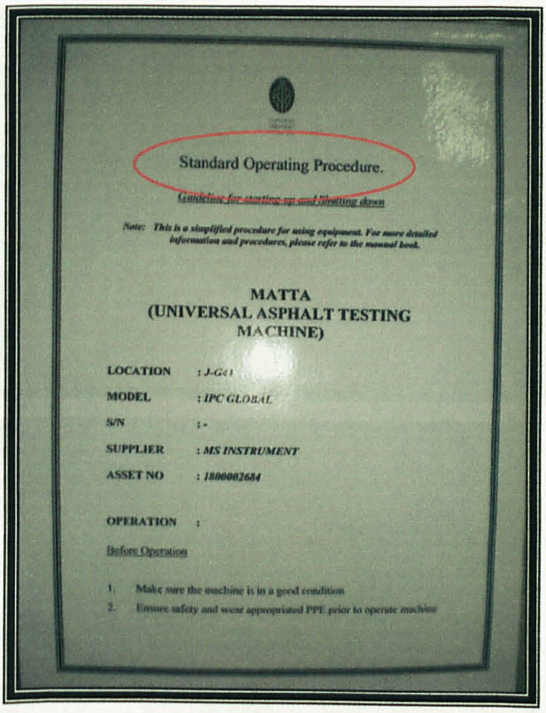
收貨人 Received by

APPENDIX C

Hazard Identification

APPENDIX D

Examples of the Standard Operating Procedure



Standard Operating Procedure.

Guideline for starting up and Shutting down

Note: This is a simplified procedure for using equipment. For more detailed information and procedures, please refer to the manual book.

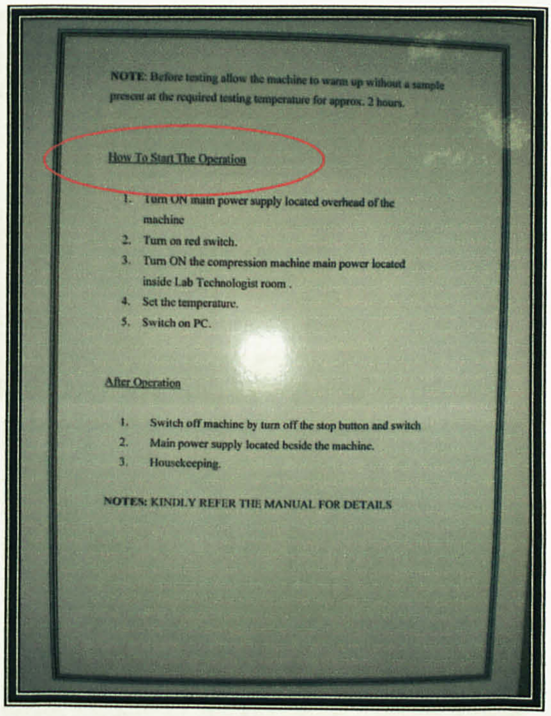
MATTA
(UNIVERSAL ASPHALT TESTING MACHINE)

LOCATION	: *J-G41*
MODEL	: *IPC GLOBAL*
S/N	: -
SUPPLIER	: *MS INSTRUMENT*
ASSET NO	: *1800002684*

OPERATION :

Before Operation

1. Make sure the machine is in a good condition
2. Ensure safety and wear appropriated PPE prior to operate machine



NOTE: Before testing allow the machine to warm up without a sample present at the required testing temperature for approx. 2 hours.

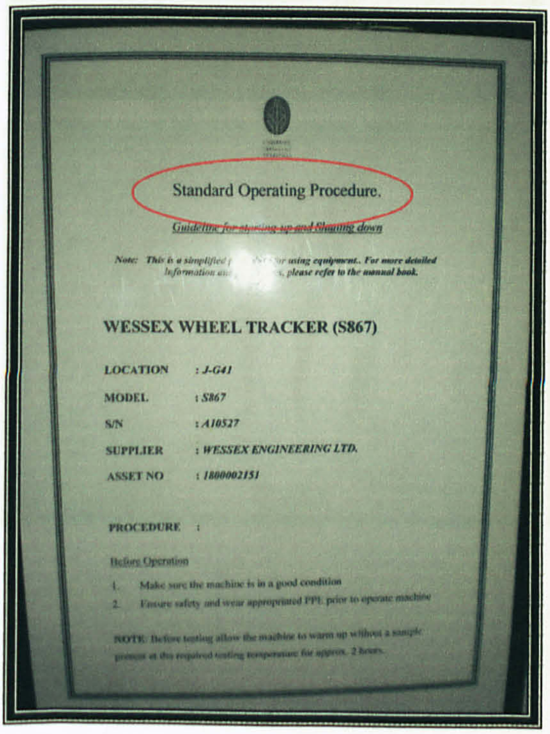
How To Start The Operation

1. Turn ON main power supply located overhead of the machine
2. Turn on red switch.
3. Turn ON the compression machine main power located inside Lab Technologist room .
4. Set the temperature.
5. Switch on PC.

After Operation

1. Switch off machine by turn off the stop button and switch
2. Main power supply located beside the machine.
3. Housekeeping.

NOTES: KINDLY REFER THE MANUAL FOR DETAILS



Standard Operating Procedure.

Guideline for starting up and Shutting down

Note: This is a simplified [illegible] for using equipment.. For more detailed information [illegible], please refer to the manual book.

WESSEX WHEEL TRACKER (S867)

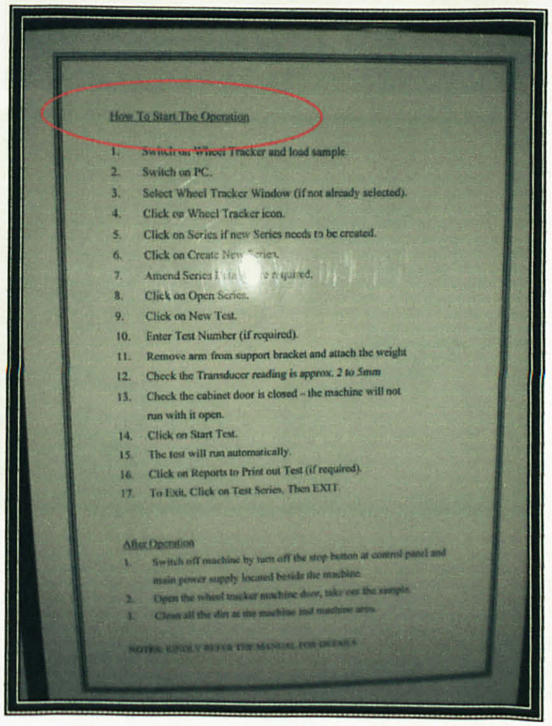
LOCATION	: *J-G41*
MODEL	: *S867*
S/N	: *A10527*
SUPPLIER	: *WESSEX ENGINEERING LTD.*
ASSET NO	: *1800002151*

PROCEDURE :

Before Operation

1. Make sure the machine is in a good condition
2. Ensure safety and wear appropriated PPE prior to operate machine

NOTE: Before testing allow the machine to warm up without a sample present at the required testing temperature for approx. 2 hours.



How To Start The Operation

1. Switch on Wheel Tracker and load sample.
2. Switch on PC.
3. Select Wheel Tracker Window (if not already selected).
4. Click on Wheel Tracker icon.
5. Click on Series if new Series needs to be created.
6. Click on Create New Series.
7. Amend Series [illegible] required.
8. Click on Open Series.
9. Click on New Test.
10. Enter Test Number (if required).
11. Remove arm from support bracket and attach the weight
12. Check the Transducer reading is approx. *2 to 5mm*
13. Check the cabinet door is closed – the machine will not run with it open.
14. Click on Start Test.
15. The test will run automatically.
16. Click on Reports to Print out Test (if required).
17. To Exit, Click on Test Series. Then EXIT.

After Operation

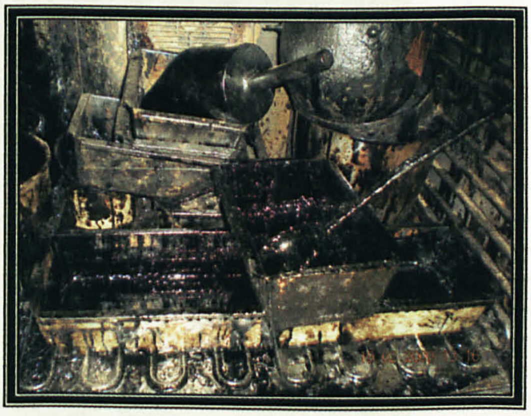
1. Switch off machine by turn off the stop button at control panel and main power supply located beside the machine.
2. Open the wheel tracker machine door, take out the sample.
3. Clean all the dirt at the machine and machine area.

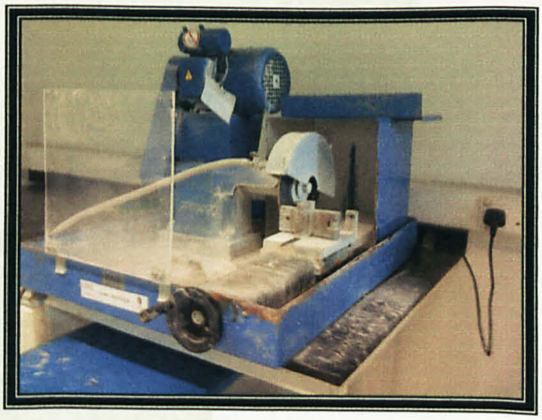
NOTES: KINDLY REFER THE MANUAL FOR DETAILS

APPENDIX E

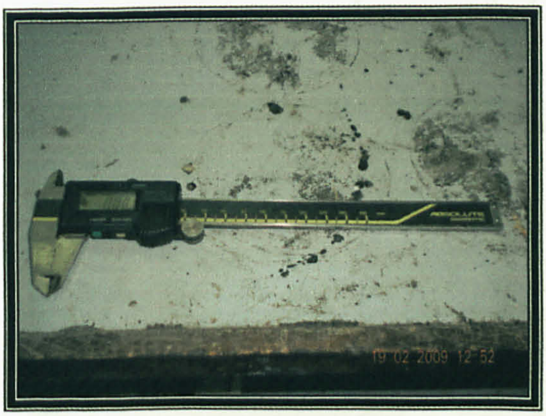
Images of the Tools



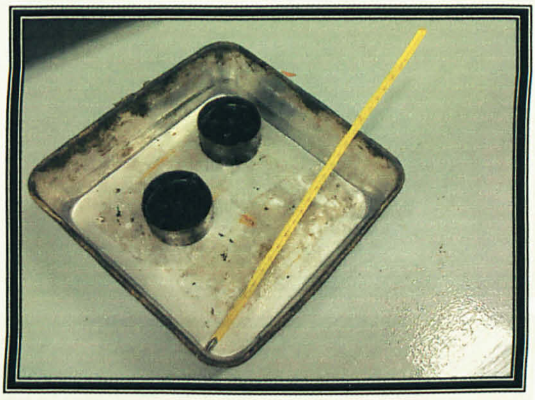


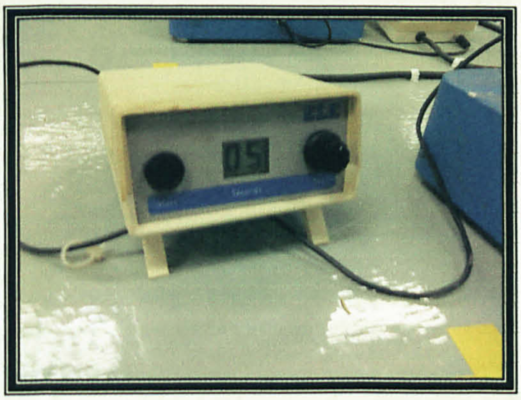
Images of the Tools

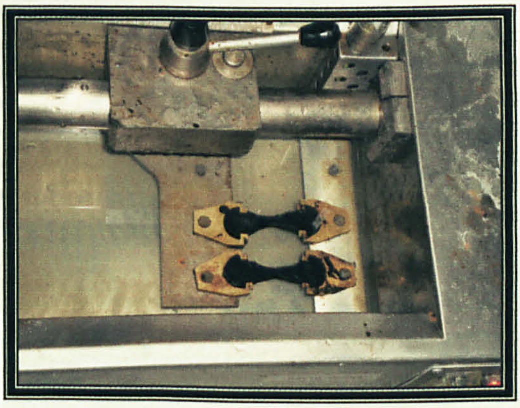


APPENDIX F

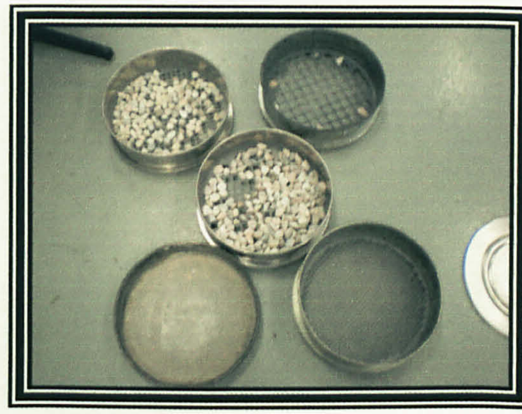
Images of the Laboratory Works

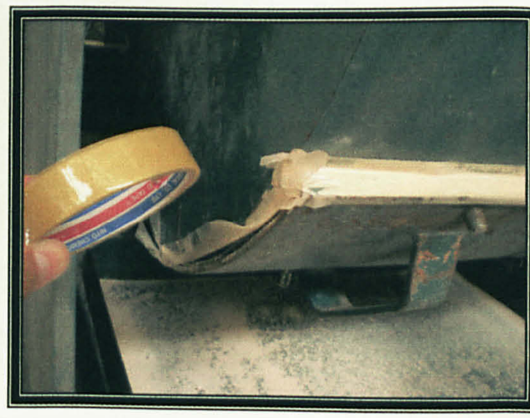




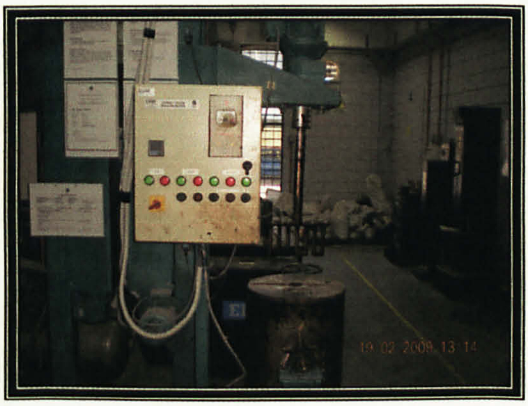


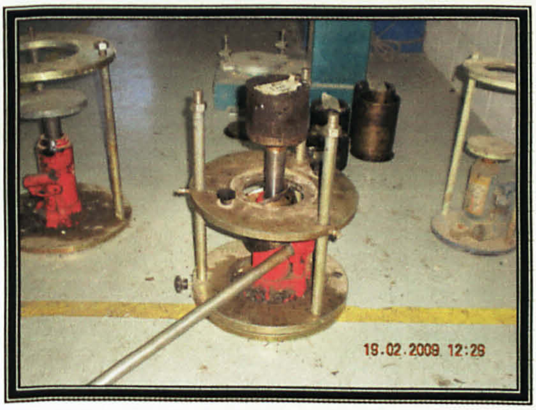
Images of the Laboratory Works

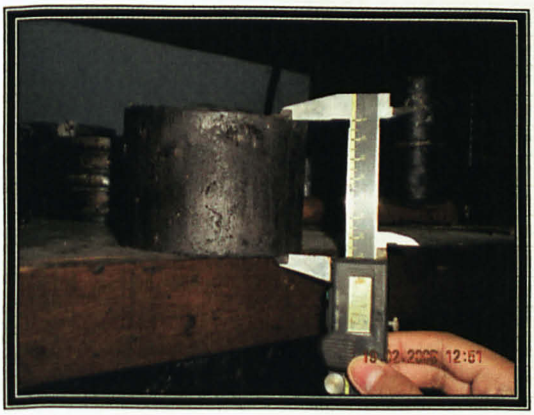




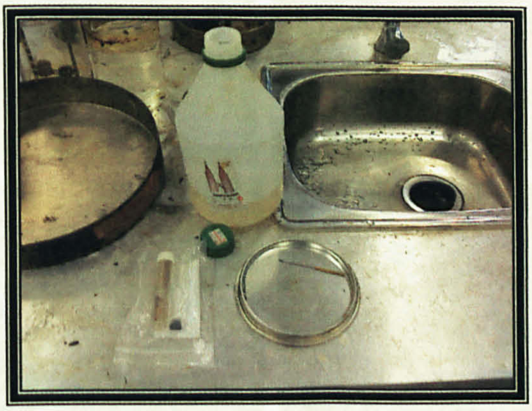
Images of the Laboratory Works



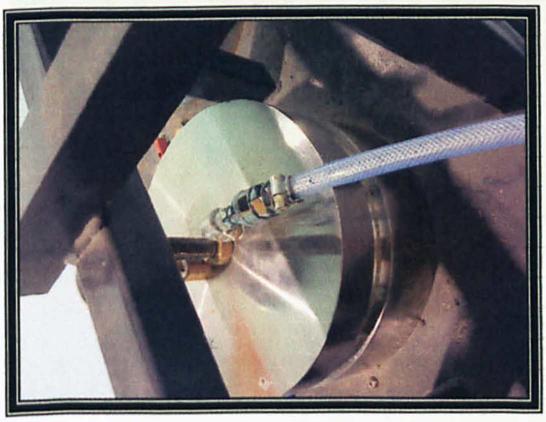


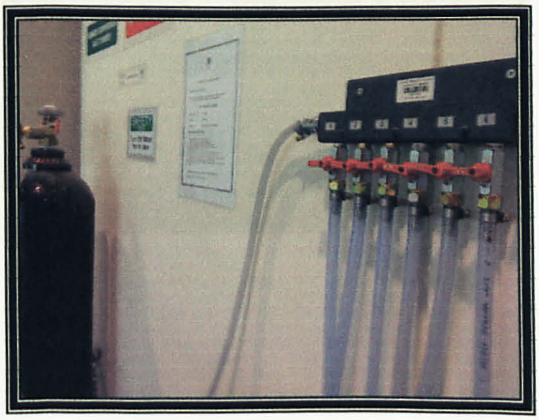


Images of the Laboratory Works

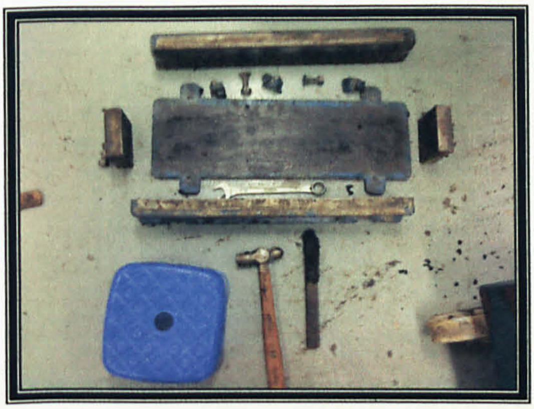


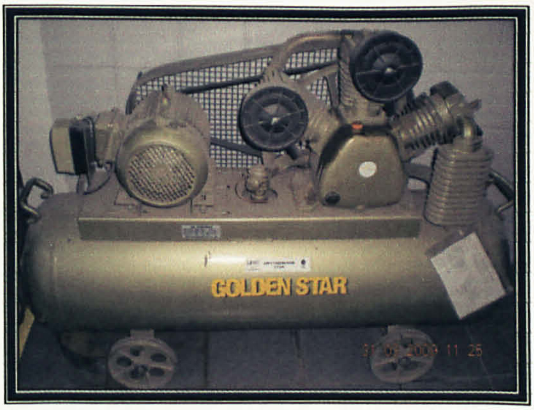
Images of the Laboratory Works





Images of the Laboratory Works





Images of the Laboratory Works

Images of the Laboratory Works